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ECLIPSES

Uncovering the science behind these incredible celestial events

YOUR GUIDE TO THE 2024 TOTAL ECLIPSE

HOW TO WATCH SAFELY

ANCIENT ASTRONOMERS

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ECLIPSES

Since humankind first began to study the skies, eclipses have fascinated and terrified astronomers in equal measure. Yet while it is easy to appreciate why many ancient civilisations viewed these awe-inspiring events as omens of disaster, thousands of years of closer examination have uncovered the science behind solar and lunar eclipses, and today we are able to predict them with incredible accuracy. However, it isn't just Earth that can find itself cast into shadow: other planets also experience eclipses. In the following pages you will discover everything you ever wanted to know about these rare celestial alignments, tour the surface of the Moon, examine the depths of the Sun and meet the pioneers who dedicated their lives to enhancing our understanding of the stars.

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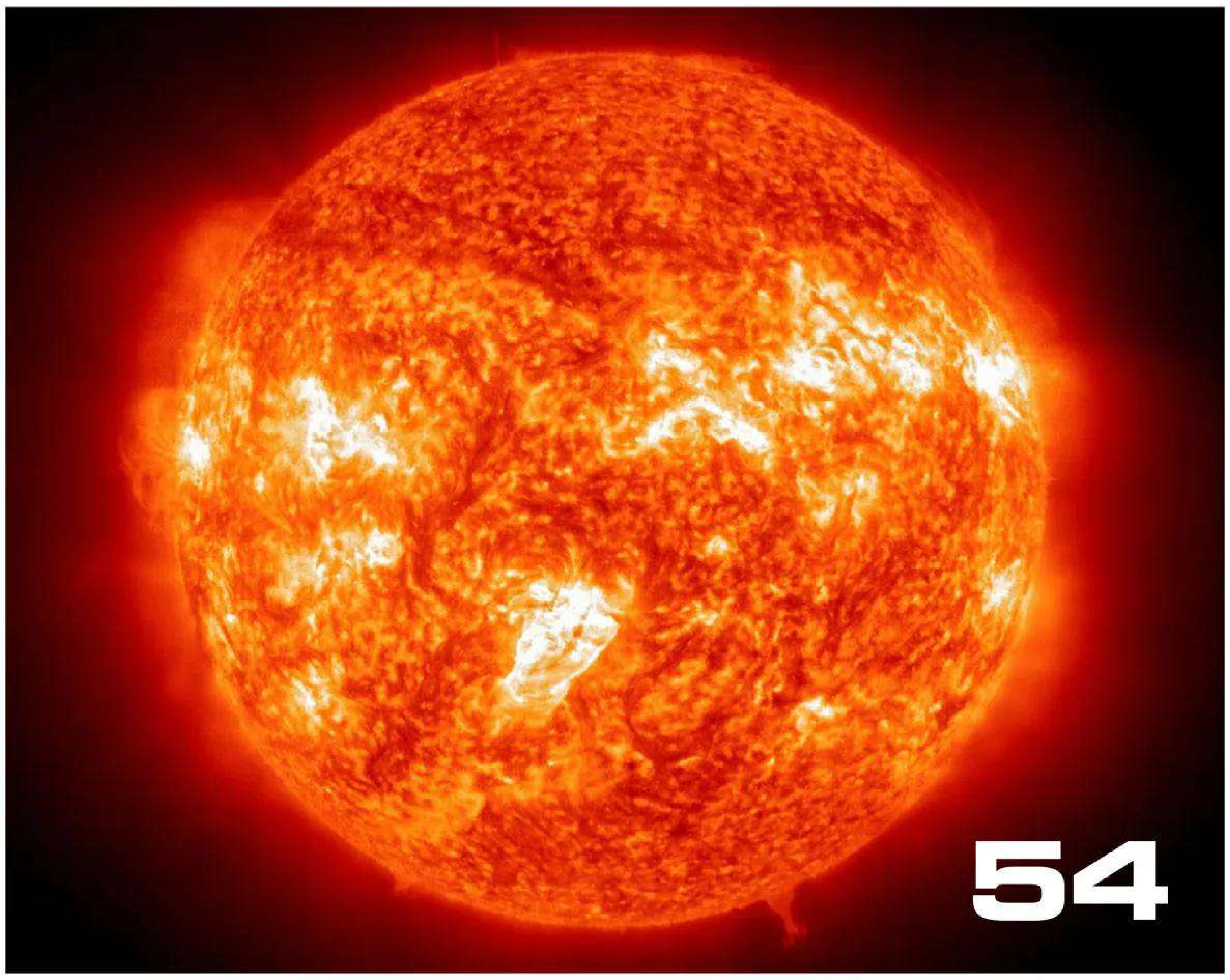
SHADOW OF HISTORY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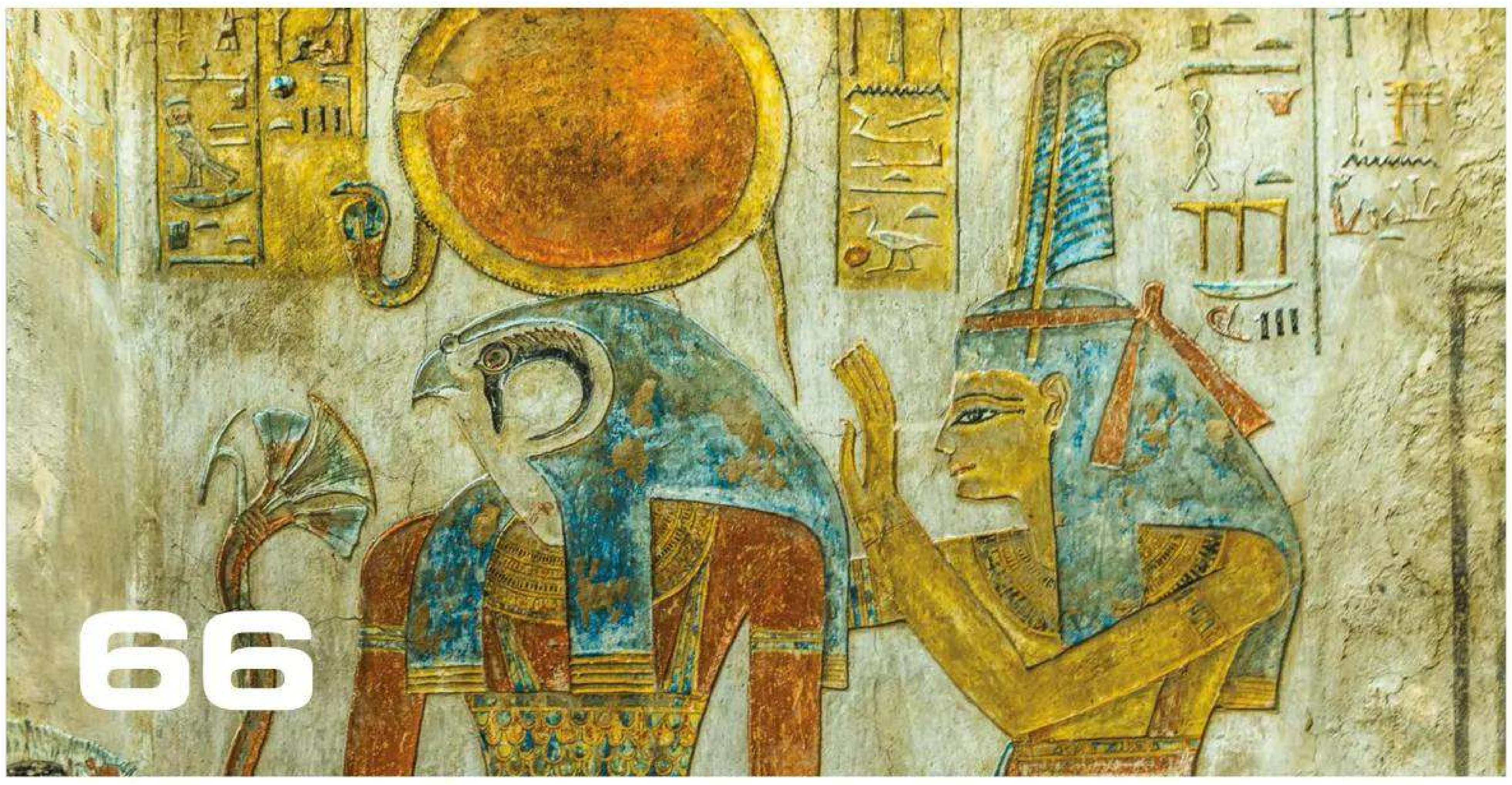
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SECTION 1
THE HEAVENS ALIGN

COMPLETE GUIDE TO THE MOON

Even though we know more about our natural satellite than any other celestial body – and have even visited it – the Moon continues to fascinate us

WORDS SHANNA FREEMAN

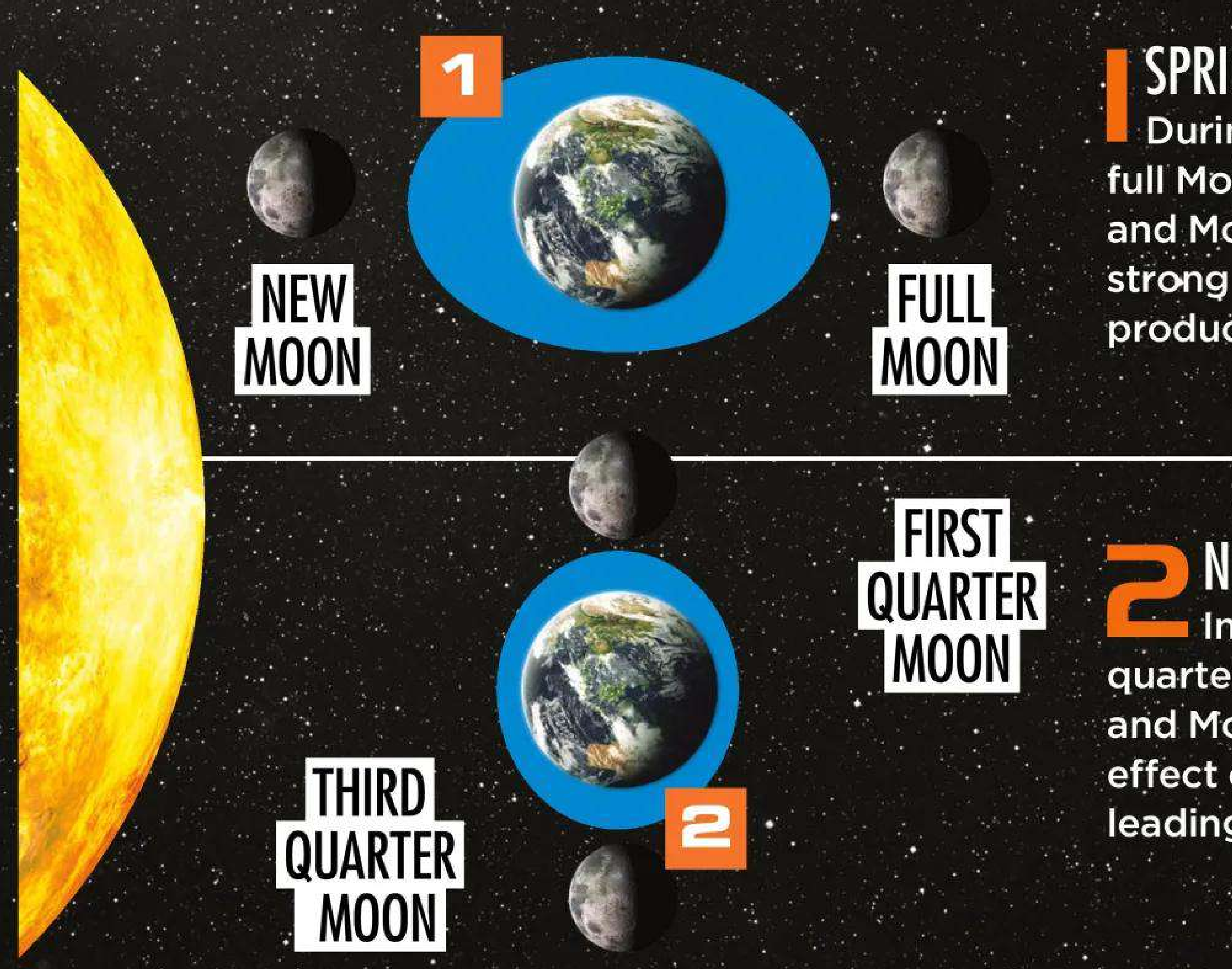
Because we can easily discern features on the Moon with the naked eye, it's been a source of wonder to us since ancient times. The Moon is the brightest object in our sky after the Sun and influences everything from our oceans to our calendars. It's always been 'the Moon' because we didn't know that there were any others. Once Galileo discovered in 1610 that Jupiter had satellites we've used the word 'moon' to describe celestial bodies that orbit larger bodies, which in turn orbit stars. Since the Moon has always been so present it might not seem worth studying, yet there's a reason why we continue to return to it – we still have plenty to learn from our satellite.

The Moon is the fifth-largest and second-densest satellite in the solar system. Its diameter is 27 per cent of Earth's at 3,476 kilometres (2,160 miles), while its mean density is 60 per cent that of Earth's. This makes the Moon the largest satellite in size relative to the planet that it orbits. The Moon is also unusual because

"THE MOON IS THE FIFTH-LARGEST AND SECOND-DENSEST SATELLITE IN THE SOLAR SYSTEM"

THE MOON AND TIDES

Along with the Sun, the Moon exerts serious force on Earth's tides. Whether the tides vary widely or not much at all has a lot to do with the interactions between the solar and lunar cycles. When they are together, their combined effects produce tidal variations called spring tides (high tides are very high and low tides are very low). If the Sun and Moon are on the opposite sides of the sky, they nullify each others' effects, producing neap tides, which have little variation.



1 SPRING TIDE
During a new and a full Moon, both the Sun and Moon exert a strong effect, producing spring tides.

2 NEAP TIDE
In first and third quarter Moon, the Sun and Moon have little effect on tidal range, leading to neap tides.

MEASURING UP THE MOON BY ITS DIAMETER

GANYMEDE
Jupiter
5,268 kilometres (3,300 miles)

TITAN
Saturn
5,150 kilometres (3,200 miles)

CALLISTO
Jupiter
4,821 kilometres (3,000 miles)

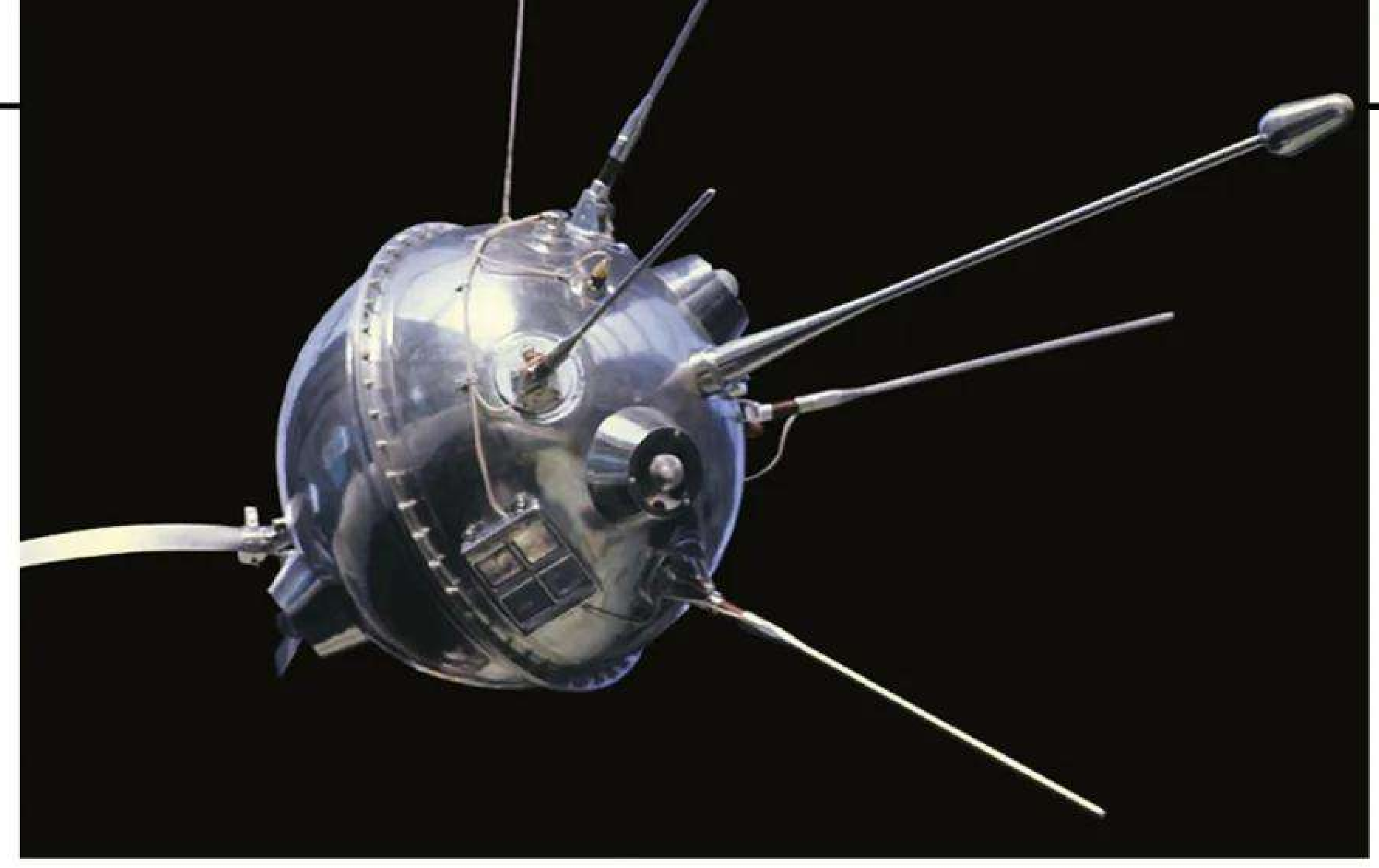
IO
Jupiter
3,642 kilometres (2,300 miles)

THE MOON
Earth
3,476 kilometres (2,160 miles)

EUROPA
Jupiter
3,122 kilometres (1,940 miles)

TRITON
Neptune
2,700 kilometres (1,700 miles)

TITANIA
Uranus
1,578 kilometres (980 miles)



its orbit is more closely aligned to the plane of the ecliptic — the plane in which Earth orbits. Most planetary satellites orbit closer to their planet's equatorial plane, but the Moon is inclined from the plane of the ecliptic by approximately 5.1 degrees.

Its average distance from Earth is 384,400 kilometres (239,000 miles), and it completes an orbit once every 27.3 days. The Moon is in synchronous rotation with Earth (its rotation and orbital period are the same) so the same side is almost always facing our planet. This is called the 'near side' of the Moon, while the opposite side is the 'far' or 'dark' side, although it gets illuminated just as often as the near side. This hasn't always been the case; the Moon used to rotate faster but the influence of Earth caused it to slow and become locked.

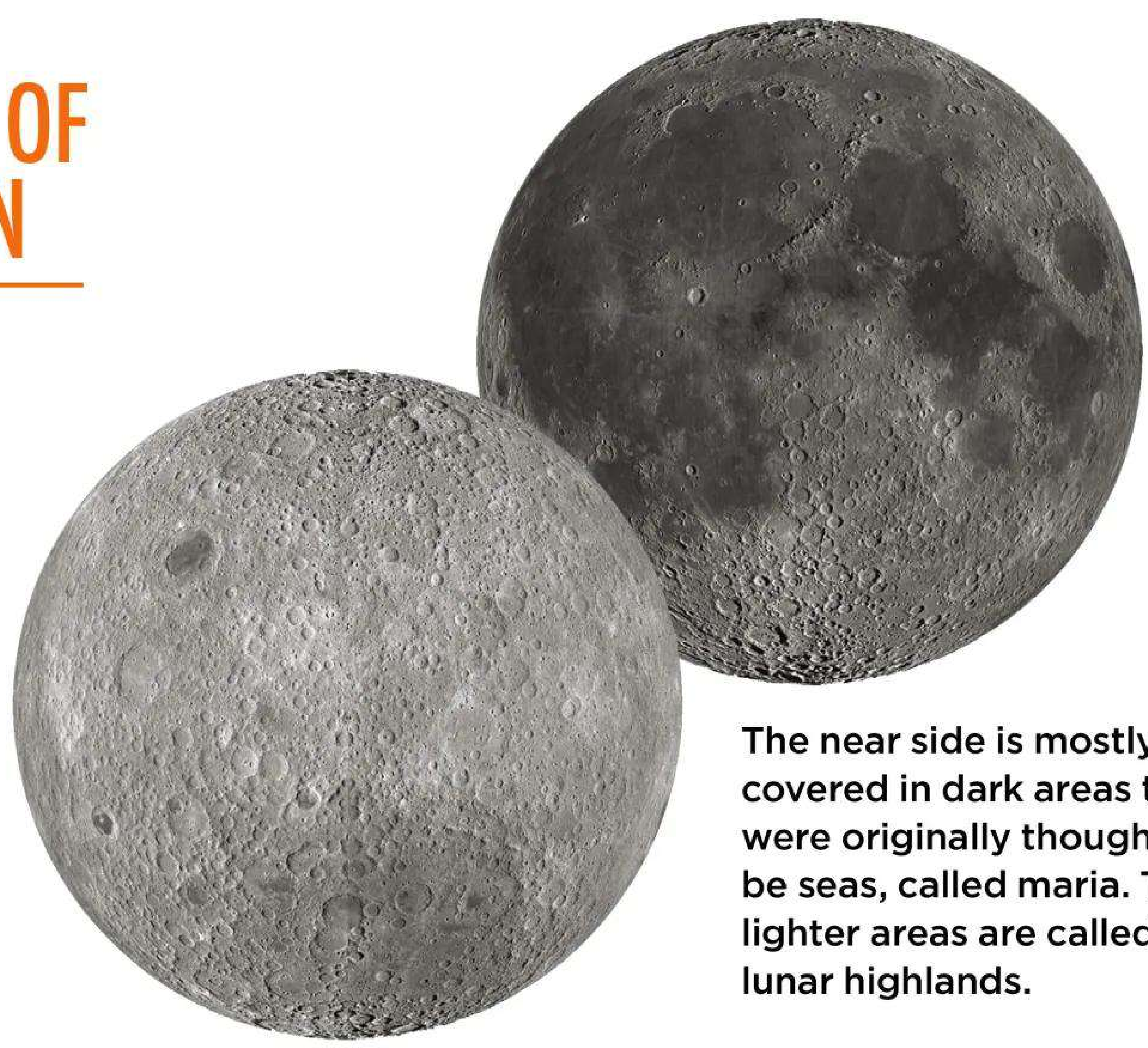
Although we say that we can only see one side of the Moon at a time, that's not strictly true. The Moon's orbit isn't quite circular — it has an eccentricity of 0.0549. The Moon also wobbles a bit along its orbit. These two factors cause some variations in how much of the Moon that we see, called librations. When the Moon is closest to Earth (called the perigee) it orbits slightly slower than it rotates. This means that we can actually get a glimpse of about eight degrees of longitude of its eastern far side. When the Moon is at its furthest point away in its orbit (the apogee) its orbit is slightly faster than its rotation. So we get a glimpse of eight degrees of longitude on its western far side. This is called longitudinal libration.

The Moon also appears to rotate towards and away from Earth. This is due to the 5.1-degree inclination of its orbit, as well as the 1.5-degree tilt of the Moon's equator to the plane of the ecliptic. This results in us seeing about 6.5 degrees of latitude on the far side along both the sides of the poles. The Moon's orbit also means that it appears to move about 13 degrees across the sky each day, and this movement accounts for the lunar phases.

The Moon's gravitational pull has a strong effect on Earth, the most obvious of which is the tides. High tide occurs when the level of water at the coastline rises, and low tide occurs when the water rushes further out. While some coastlines experience one high tide and one low tide per day (of equal strength), others have different strengths, timing and numbers of tides. Measuring and predicting these tides is vital for everything from fishing to navigating intercoastal waterways. We use the term 'tides' to describe oceanic tides, but tides also occur on a smaller level in lakes as well as in Earth's atmosphere and crust.

Scientists believe that the Moon formed when a huge celestial body about the size of Mars (which has been given the name Theia) impacted with a young Earth. This is known as the giant impact hypothesis. This force sent debris out into Earth's orbit, which fused to form the Moon. However, in 2012 an analysis of rock samples taken from the Moon during the Apollo missions showed that the Moon's composition is almost identical to Earth's. This calls the giant impact hypothesis into question because previously we thought that at least some of the Moon's material had to have come from Theia.

TWO SIDES OF THE MOON



As opposed to the near side, the far side is covered with craters and very little maria. This may be because it's hotter on that side, or because it experienced a collision.

The near side is mostly covered in dark areas that were originally thought to be seas, called maria. The lighter areas are called the lunar highlands.

HOW THE MOON MIGHT HAVE BEEN MADE

1 THEIA NEARS EARTH
A Mars-sized object is on an unalterable collision course with early planet Earth.

2 EARTH IS HIT
The impactor hit Earth in a head-on collision, vaporising both Theia and the mantle of Earth.

3 MATERIAL IS THROWN OUT
The vaporised material from both bodies mixed and was thrown outwards into space.

4 DEBRIS GATHERS
Smaller objects began to condense out of the vapour while continuing to orbit around Earth.

5 THE MOON TAKES SHAPE
Many of the smaller objects stuck together to form a protomoon in orbit around Earth.

6 OUR COMPANION IS FORMED
Eventually all the pieces came together to form the basis of the Moon that we see today.

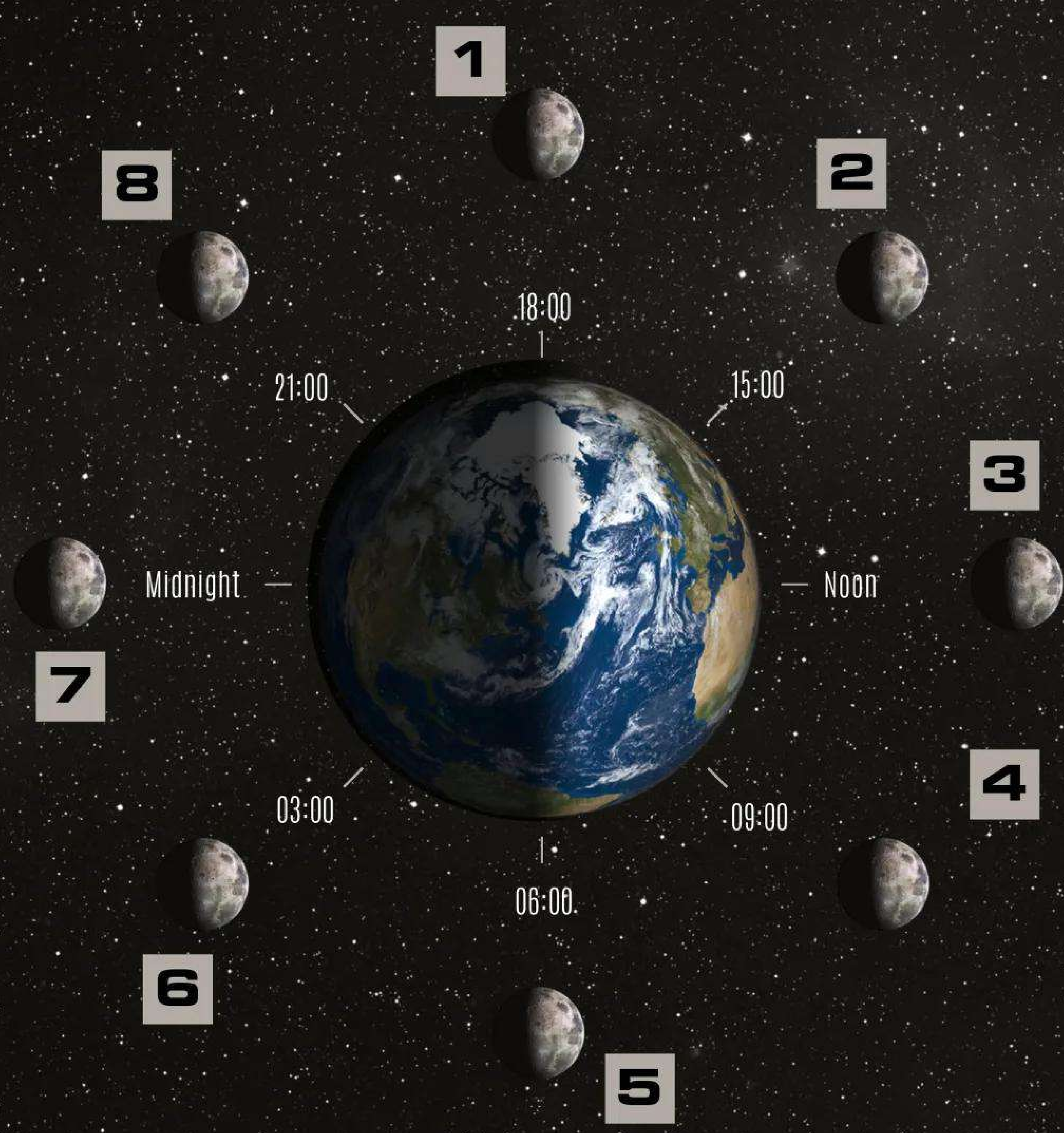
THE MOON'S ORBIT

1 FIRST QUARTER
Half of the Moon is visible in the afternoon and early evening.

2 WAXING CRESCENT
Up to 49 per cent of the Moon is visible in the afternoon and after dusk.

3 NEW MOON
The first visible crescent in the southern hemisphere, seen after sunset.

4 WANING CRESCENT
Up to 49 per cent is visible just before dawn and in the morning.



5 THIRD QUARTER
Half of the Moon is visible in the late evening and the morning.

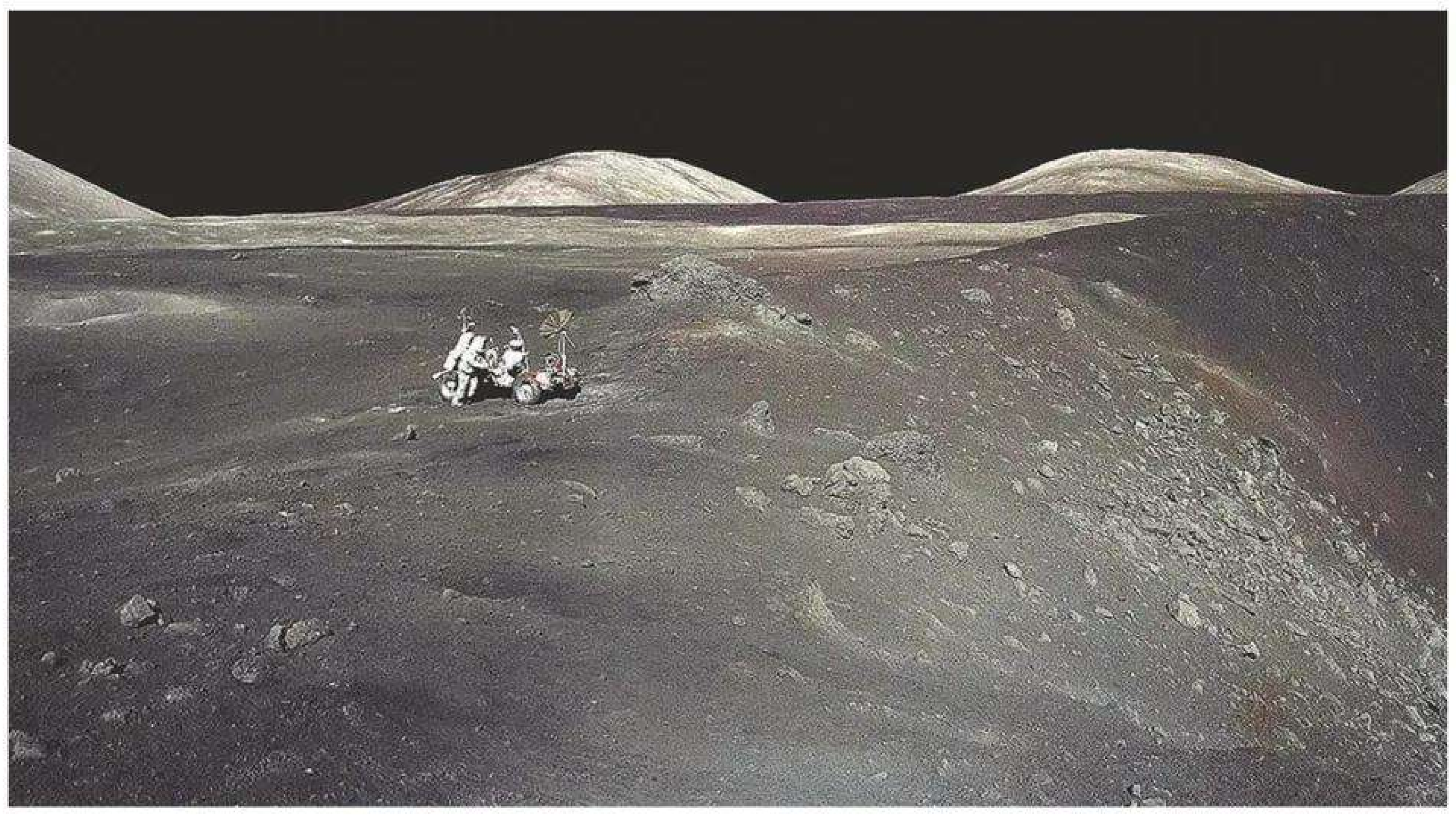
6 WANING GIBBOUS
Between 51 and 99 per cent of the Moon is visible for most of the evening and in the early morning.

7 FULL MOON
The entire Moon is visible all night long.

8 WAXING GIBBOUS
Between 51 and 99 per cent is visible in the later afternoon and most of the evening.

INSIDE AND OUT

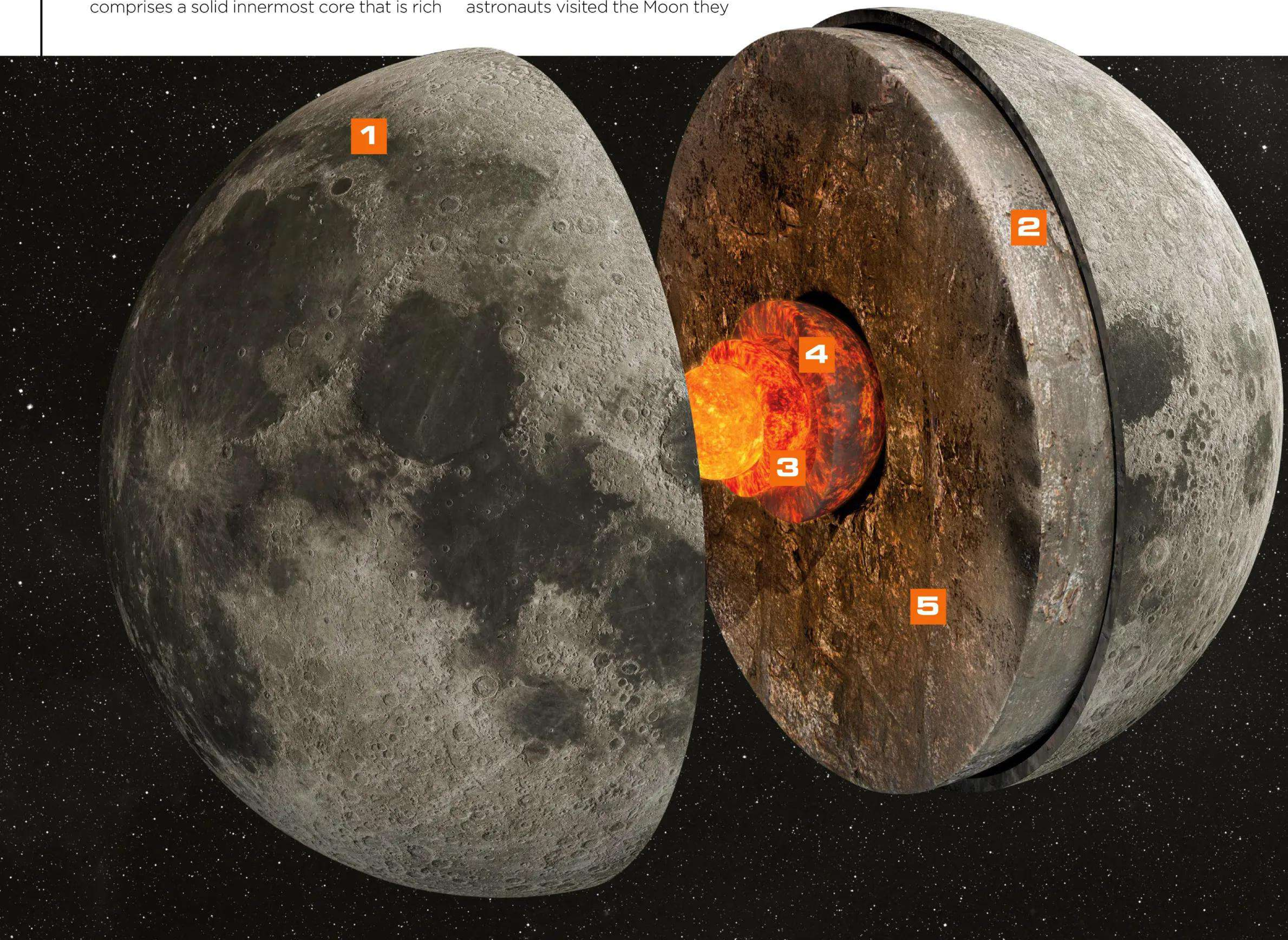
Earth's natural satellite shares some remarkable similarities with our home planet



Although the Moon may seem like a solid rock, it's actually differentiated like Earth; it has a core, a mantle and a crust. The Moon's structure likely came from the fractional crystallisation of a magma ocean that once covered it. This probably happened not long after the Moon was formed about 4.5 billion years ago. As the magma ocean cooled, its composition changed as the different minerals within the melt crystallised into solids. The denser materials sank, forming the mantle, while less-dense materials floated on top and coagulated to form the crust.

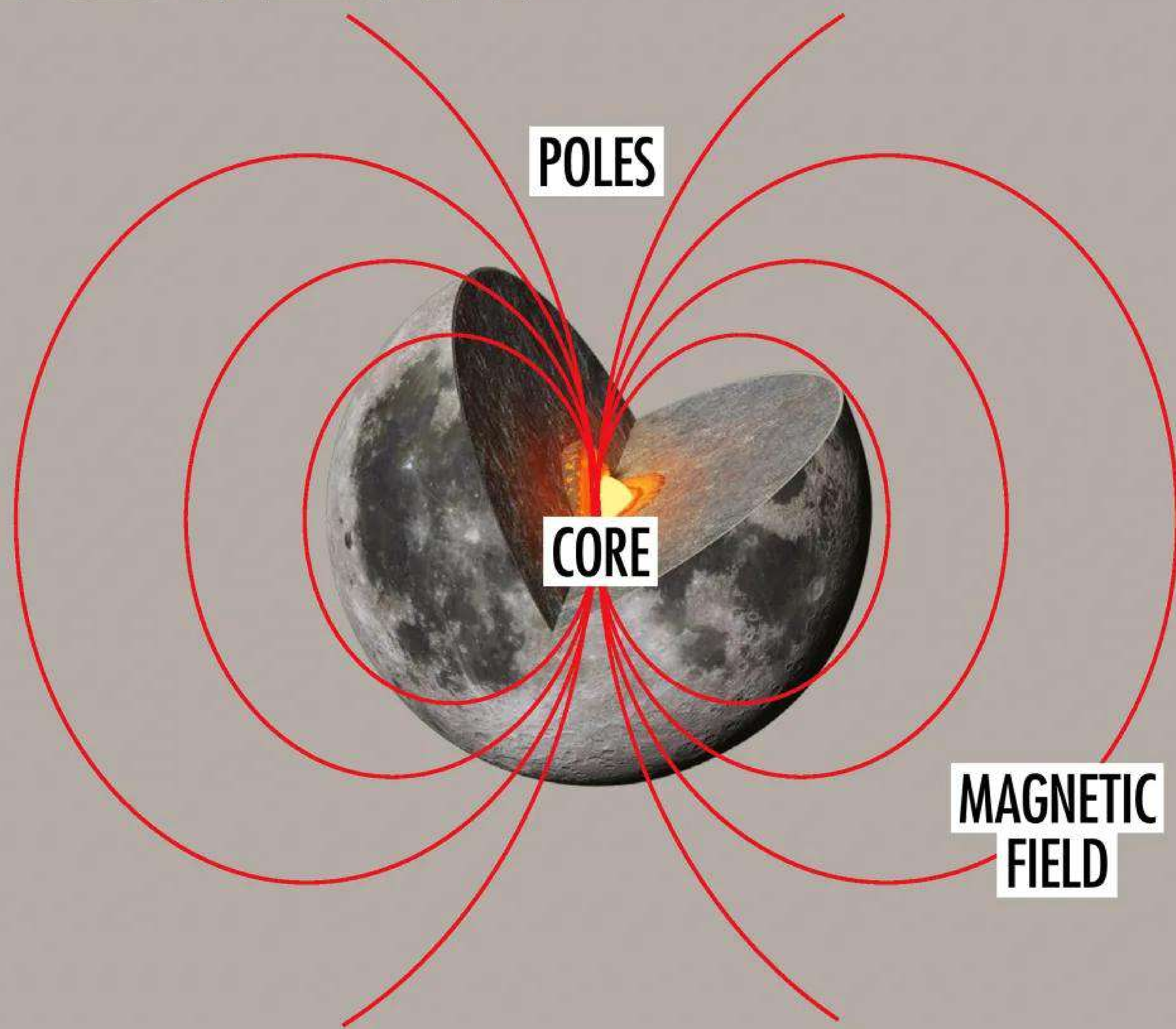
The core is probably very small, with a radius about 20 per cent the total size of the Moon. By contrast, most differentiated celestial bodies have cores about 50 per cent of their total size. The core itself comprises a solid innermost core that is rich in iron as well as nickel and sulphur, with a radius of 240 kilometres (150 miles). This is surrounded by a fluid outer core with about a 300-kilometre (186-mile) radius. Between the core and the mantle there's a boundary layer of partially melted iron that has a 500-kilometre (300-mile) radius. It is also known as the lower mantle. The upper mantle is mafic — rich in magnesium and iron and topped by a crust of igneous rock called anorthosite. It mainly includes aluminium, calcium iron, magnesium and oxygen, with traces of other minerals. We estimate the crust is around 50 kilometres (31 miles) thick.

The Moon has no plate tectonics, but it does have seismic activity. When astronauts visited the Moon they discovered that there are moonquakes – the Moon's equivalent of earthquakes. Moonquakes aren't nearly as strong as earthquakes, but they can last longer because there's no water to lessen the effects of the vibrations. Seismometers showed that the strongest moonquakes are about 5.5 on the Richter scale. There are four different types of moonquakes: shallow, deep, thermal and meteorite. Shallow ones occur 20 kilometres (12 miles) below the surface, while deep moonquakes can be as deep as 700 kilometres (435 miles). These deep



THE MAGNETIC FIELD MYSTERY

The Moon has an external magnetic field. It's less than one-hundredth that of Earth's magnetic field and it's not a dipolar magnetic field like Earth, which has a field that radiates from the north and south poles. Researchers believe the Moon once had a dipole magnetic field created by a dynamo — a convecting liquid core of molten metal. But we aren't sure what powered that dynamo. It could have worked like Earth's dynamo, which powers itself as elemental radioactive decay maintains convection in the core. The Moon could also have had a dynamo powered by the cooling of elements at the core.



1 CRUST The crust is igneous rock called anorthosite. It's about 50 kilometres (31 miles) thick.

2 MANTLE The main mantle is mafic — rich in magnesium and iron.

3 INNER CORE The inner core is rich in iron, with a radius of 240 kilometres (150 miles), and it's much smaller than the cores of most terrestrial bodies.

4 OUTER CORE The fluid outer core has a 300-kilometre (186-mile) radius.

5 PARTIAL MELT This partially melted layer is mostly iron, with a radius of 500 kilometres (300 miles).

moonquakes are probably related to stresses on the Moon caused by its eccentric orbit and gravitational interactions between it and Earth. Thermal earthquakes occur when the crust of the Moon heats and expands. Shallow moonquakes are the strongest and most common. Nearly 30 were recorded between 1972 and 1977 by seismometers on the surface. This seismic data has helped us to determine the precise make up of the Moon's internal composition.

The dominating feature on the near side of the Moon's surface, called maria, are the result of ancient volcanic activity. These vast, dark plains are basalts — igneous rock that formed after lava erupted due to partial melting within the mantle. These basalts show that the Moon's mantle is much higher in iron than Earth's and has a varied composition. Some basalts are very high in titanium, while others are higher in minerals like olivine.

These basalt maria have influenced the Moon's gravitational field because they're so rich in iron. The gravitational field contains mascons, positive gravitational anomalies that influence how spacecraft orbit the Moon. The maria can't explain all of the mascons that have been tracked by the Doppler effect on the radio signals emitted by spacecraft that orbit the Moon, and there are also some large maria without associated mascons.

THE MOON BY NUMBERS

400

How many times bigger the Sun is than the Moon. It's also about 400-times further away from Earth, which is why they look the same size in the sky.

29.5 DAYS

The length of a lunar month, longer than the amount of time it takes the Moon to orbit Earth because Earth is moving too.

12

The number of people who have set foot on the Moon.

3.8 CENTIMETRES

The distance the Moon moves away from Earth each year (equivalent to 1.5in).

13 HOURS

The amount of time it takes to reach the Moon by rocket.

16.6 KILOGRAMS

The amount (36.6lb) you would weigh on the Moon if you weighed 100 kilograms on Earth.

ON THE SURFACE

The surface of the Moon is about contrasts: light and dark, hot and cold

The landscape of the Moon is dominated by three main features: maria, terrae and craters. The basalt maria appear dark due to their high iron content and are much more prevalent on the near side of the Moon. Other volcanic features on the surface include domes and rilles. Domes are shield volcanoes that are round and wide with gentle slopes, while rilles are twisting sinuous formations caused by channels of flowing lava.

The lighter areas on the Moon are called terrae, or lunar highlands. They are made up of anorthosite, the type of igneous rock that dominates the overall crust of the Moon. While this type of rock can be located in some places on Earth, it's not generally found on the surface due to plate tectonics and deposits. These highlands reflect light from the Sun and make it appear that the Moon is glowing at night.

Both the maria and terrae have impact craters that were formed when asteroids and comets struck the surface of the Moon. These craters range in size from very tiny to massive. It is estimated that there are around

The last manned mission to the Moon took place in December 1972

A LUNAR WORLD TOUR

1 OCEANUS PROCELLARUM This mare is so large it was deemed to be an ocean. It covers about 4 million square kilometres (1.5 million square miles).

2 LUNA 9 Launched by the Soviet space programme on 31 January 1966, this site marks the first soft landing of an unmanned spacecraft on the Moon's surface.

3 SURVEYOR 1 Launched on 30 May 1966, the first American soft Moon landing happened here.

4 COPERNICUS This crater is well known because it can be easily seen from Earth. It is a younger crater, about 800 million years old, with a prominent system of ejecta rays.

5 VALLIS ALPES This lunar valley bisects a mountain range called the Montes Alpes and extends over 166 kilometres (103 miles).

6 MONTES APENNINUS This mountain range is about 600 kilometres (370 miles) long and has peaks up to five kilometres (three miles) high.

7 SCHRÖDINGER This huge crater near the south pole can only be viewed from orbit. It is 312 kilometres (194 miles) in diameter.

8 APOLLO 11 Neil Armstrong and Buzz Aldrin became the first men to set foot on the Moon on 21 July 1969 as part of NASA's Apollo programme.

9 TYCHO This distinctive crater has ejecta rays visible from Earth during a full Moon that reach over 1,000 kilometres (621 miles) away from the crater.

10 MARE TRANQUILLITATIS This mare was the landing site for the Apollo 11 spacecraft. It is slightly bluish because it has a high metal content.

EXPLORING THE MOON: THE PAST

APOLLO 11 21 July 1969
NASA astronauts Buzz Aldrin and Neil Armstrong became the first humans to set foot on another body in space when they landed on the Moon in 1969.

APOLLO 12 19 November 1969
The second spacecraft to land on the Moon, Apollo 12, used a Doppler effect radar technique to land the spacecraft within walking distance of the Surveyor 3 probe, which had landed on the lunar surface about two years prior.

APOLLO 14 5 February 1971
The commander on board the third spacecraft to land on the Moon was Alan Shepard, who a decade earlier on 5 May 1961 had become the second person in space after Yuri Gagarin and the first American as part of the Mercury programme.

APOLLO 15 30 July 1971
NASA deemed this Moon landing the most successful so far out of its manned missions. It is also known as the first of the longer missions to the Moon, called 'J missions', staying for three days.

APOLLO 16 21 April 1972
Apollo 16 was the first spacecraft to land in the highlands on the Moon, which let the astronauts gather older lunar rocks.

APOLLO 17 11 December 1972
This last manned mission to the Moon carried the Traverse Gravimeter Experiment, which measured relative gravity at different sites on the Moon.

LUNA 1 4 January 1959
This Soviet probe was the first to reach the vicinity of the Moon and the first to break out of geocentric orbit, but it didn't impact the Moon as had originally been planned.

LUNA 21 15 January 1973
This Soviet spacecraft landed on the Moon and carried a lunar rover, Lunokhod 2. It performed numerous experiments and sent back more than 80,000 images.

LUNA 24 22 August 1976
This was the last of the Luna missions, landing near Mare Crisium to recover samples. It was the last spacecraft to have a soft landing on the Moon until 2013.

300,000 craters on the near side of the Moon that are wider than one kilometre (0.62 miles). The largest impact crater, called the South Pole-Aitken Basin, is about 2,500 kilometres (1,550 miles) in diameter and 13 kilometres (eight miles) deep. The biggest craters also tend to be the oldest, and many are covered in smaller craters. Younger craters have more sharply defined edges, while older ones are often softer and rounder. If the impact was especially large, material may be ejected from the surface to form secondary craters.

In some cases, the basalt eruptions flowed into or over large impact craters called basins. In general, the terrae have far more craters because the maria are younger in age than the terrae. While the Moon isn't much younger than Earth, our planet has processes that continue to change its surface over time, like erosion and plate tectonics. The Moon doesn't experience these, which is why some impact craters are up to 500 million years older than the basalt filling them.

The loose soil on the Moon is called regolith. It's powdery and filled with small rocks. Over time, impacts from meteors, as well as space weathering (solar wind, cosmic rays, meteorite bombardment and other processes), break down the rocks and grind them into dust. Aside from the basalt and anorthosite rocks, there are also impact breccias — rock fragments that were welded together by meteor impacts — and glass globules from volcanic activity.

Although you may sometimes see the term 'lunar atmosphere', the Moon is actually considered to exist in a vacuum. There are particles suspended above the surface, but the density of the Moon's atmosphere is less than one hundred trillionth that of Earth's atmosphere. What little atmosphere there is gets quickly lost to outer space and is constantly replenished. Two processes help to replenish the Moon's atmosphere: sputtering and outgassing. Sputtering occurs when sunlight, solar wind and meteors bombard the surface and eject particles. Outgassing comes from the radioactive decay of minerals in the crust and mantles, which can release gases such as radon.

"THERE ARE PARTICLES ABOUT THE SURFACE, BUT THE DENSITY OF THE MOON'S ATMOSPHERE IS LESS THAN ONE HUNDRED TRILLIONTH OF EARTH'S"

The Moon has a very minor axial tilt, so it doesn't have seasons in the same way that we have them here on Earth. However, temperatures on the Moon can change dramatically because there's no atmosphere to trap heat, and portions of the Moon may be either in full sunlight or total darkness depending on where it is in its rotation. Full sunlight can mean temperatures of greater than 100 degrees Celsius (212 degrees Fahrenheit). But at the end of the lunar day the temperature can drop by hundreds of degrees. There are also big differences in temperatures depending on the surface features. For example, the Moon is coldest in its deepest craters, which always remain in darkness. The coldest temperature ever recorded in the Solar System by a spacecraft was measured by the Lunar Reconnaissance Orbiter in the Hermite Crater near the Moon's north pole at -248 degrees Celsius (-414 degrees Fahrenheit).

"ANALYSIS OF ROCK SAMPLES TAKEN FROM THE MOON DURING THE APOLLO MISSIONS SHOWED THAT THE MOON'S COMPOSITION IS ALMOST IDENTICAL TO EARTH'S"

INSET: The remains of the Soviet probe Luna 24 rest in Mare Crisium

American boots on the Moon ended the Space Race

© NASA

PRESENT AND FUTURE

We've been studying the Moon for thousands of years, and thanks to a host of pioneering missions we now know more about our satellite than ever before

Although there hasn't been a manned mission to the Moon since 1972, and there were no soft landings at all until 1966, we're still exploring our satellite. Currently the Lunar Reconnaissance Orbiter (LRO) is still circling the Moon. It launched on 18 June 2009 and became the first NASA mission to the Moon in more than a decade. The LRO is meant to be a precursor to future manned missions and was originally designed to spend just a year in orbit. However, the mission was extended several times. It was designed to extensively map the Moon in high resolution, explore the potential of ice in the polar regions, study deep space radiation and continue to map the surface of the Moon.

The other current NASA mission is ARTEMIS, an extension of an earlier satellite mission. Two small probes have been orbiting the Moon together since summer 2011, having previously performed lunar and Earth flybys.

The Lunar Crater Observation and Sensing Satellite (LCROSS) was launched along with the LRO and considered an inexpensive way to look for water ice, and it was successful. The LCROSS discovered ice in the Cabeus crater near the Moon's south pole after its upper stage impacted as planned on 9 October 2009. Two small spacecraft under the name GRAIL A and GRAIL B were launched on 10 September 2011 and impacted on 17 December 2012, having collected data to help understand how terrestrial planets have evolved. Japan, India and China have all dispatched lunar probes in the last six years as well.

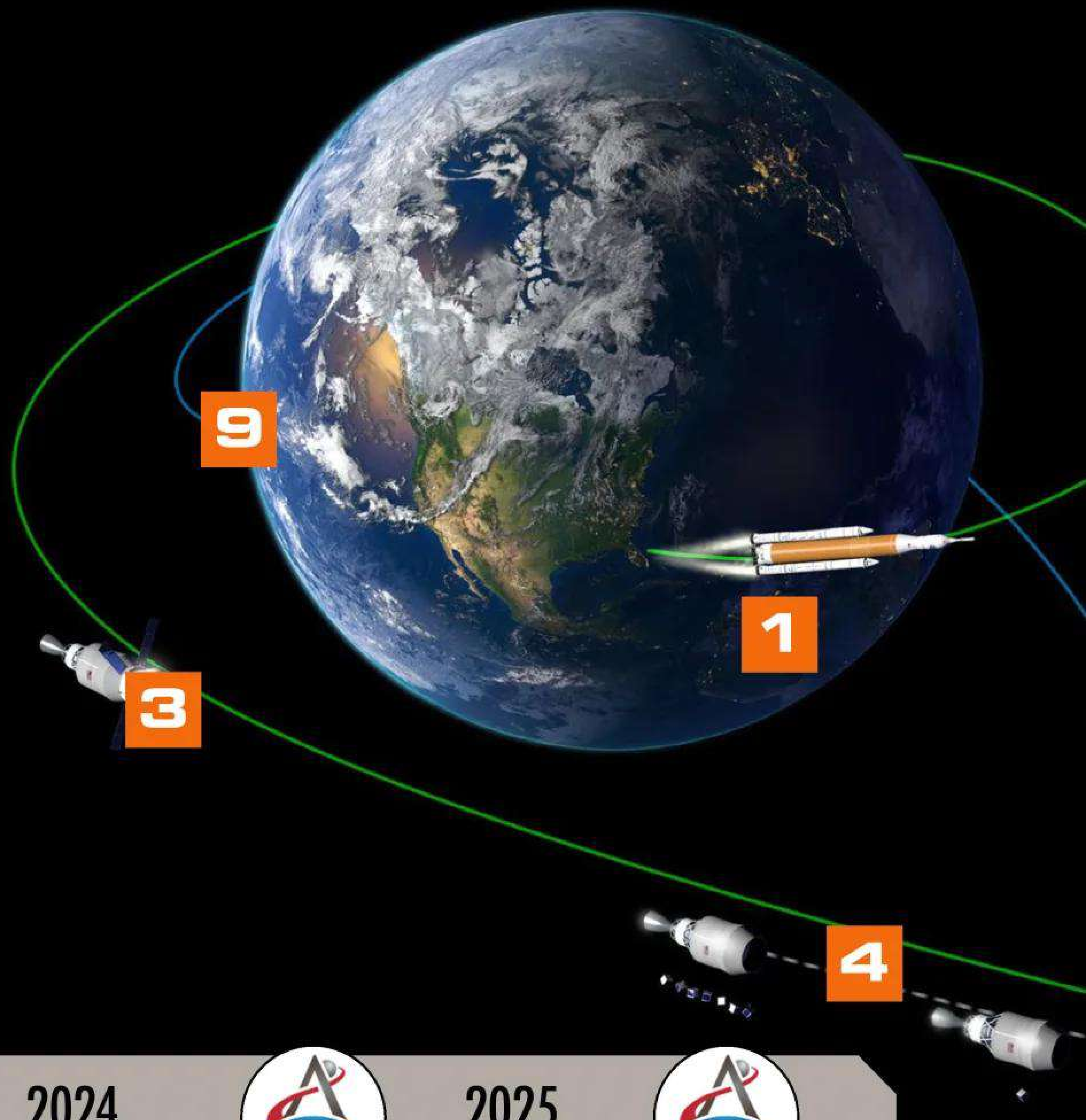
ABOVE: Humans will return to the Moon in 2025 and search for sites that would be suitable for a lunar base

EARTH TO THE MOON

Jump on board the Orion as we follow the route planned for the Artemis astronauts

LAUNCH DAY

Scheduled to launch in 2025, the third Artemis mission and second with crew on board will launch from the Kennedy Space Center in Florida. It will be monitored by the nearby Launch Control Center.



2022 ARTEMIS I

ARTEMIS I

This first mission was uncrewed in order to test the takeoff and the capsule's ability to orbit, descend and splashdown. It carried 13 small satellites to perform experiments and technology demonstrations. The craft completed flybys of the Moon on 21 November and 5 December.

2024 ARTEMIS II

ARTEMIS II

Carrying the first four Artemis astronauts, the Orion capsule will take the crew further from Earth than humans have ever travelled before. Over the approximately ten-day mission the crew will complete a lunar flyby and return to Earth, all the while evaluating the performance of the spacecraft's systems.

2025 ARTEMIS III

ARTEMIS III

This will see the next man and first woman step onto the lunar surface. Providing previous missions have been successful, the astronauts will shoot towards the Moon and then use the lunar lander to lower two people into the south polar region. They will remain on the Moon for around a week.

2 ENTERING ORBIT

Once the rocket has taken Orion into orbit, its engines will shut down and it will separate from the capsule. These rocket components will fall towards the Pacific Ocean. Orion will then deploy its solar arrays.

3 TRANS-LUNAR INJECTION

Having made it into Earth orbit, the Orion vehicle will head to the Moon. During a 20-minute burn, the engines will fire to increase the speed, displacing the spacecraft from its low-Earth orbit.

4 TO DEEP SPACE

Set on a precise trajectory, Orion will travel over 384,000 kilometres (239,000 miles). This needs to account for factors such as gravity and the movement of the Moon. Artemis I will have tested the planned path.

5 LUNAR FLYBY

A main engine burn 185 kilometres (115 miles) above the Moon's surface will put Orion on a trajectory to intercept the orbit of the planned Lunar Gateway space station, set to launch in November 2024.

6 MOON LANDING

Having docked with Gateway, the crew may need to inspect it and collect supplies. While two astronauts will stay aboard the spacecraft in orbit, the other two will transfer to a lander vehicle.

7 LUNAR EXPLORATION

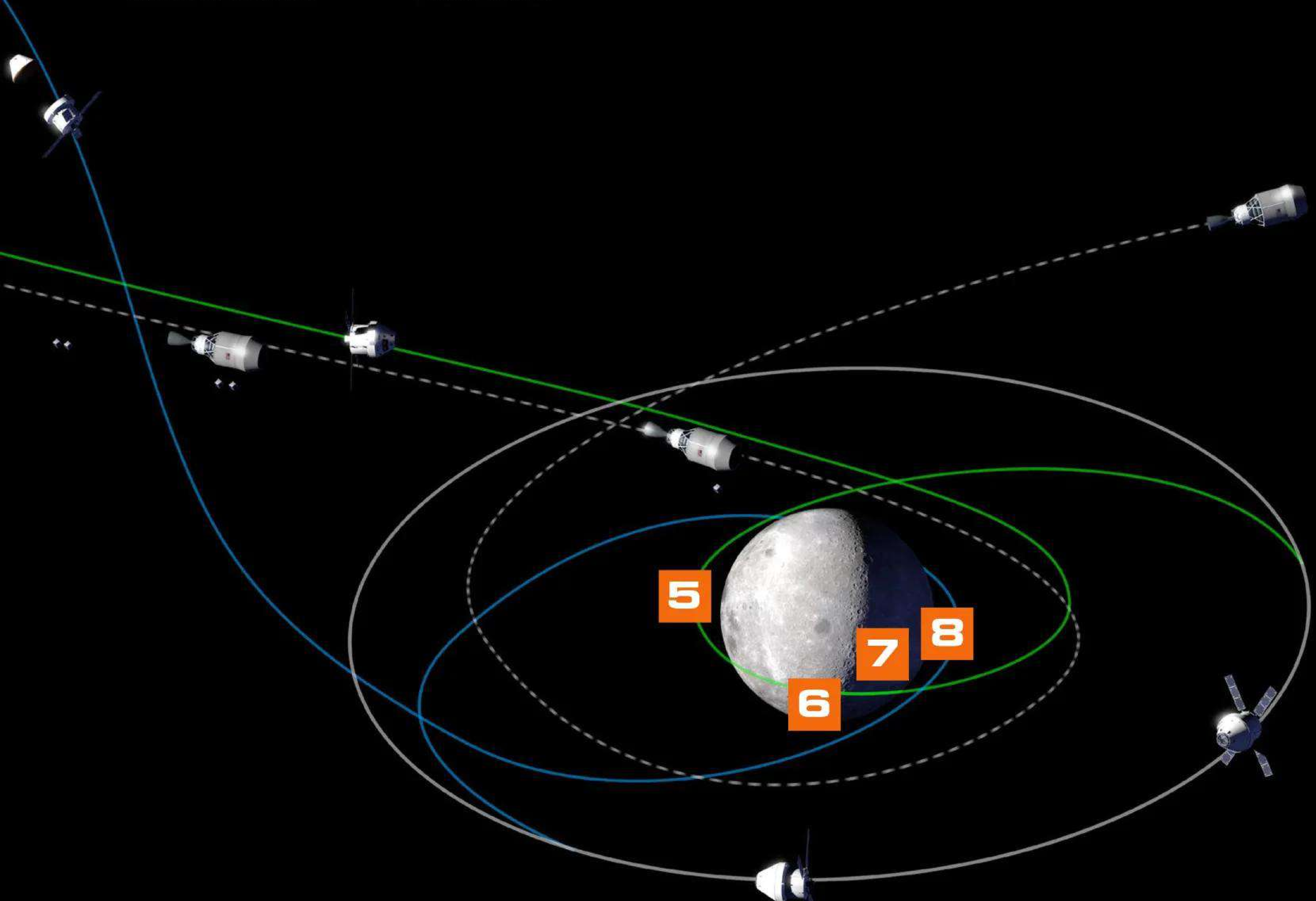
The astronauts will remain on the Moon for roughly seven days. As an area where water ice is present, they will explore the suitability of the lunar south pole for a permanent Moon base.

8 ASCENT

Having carried out experiments on the Moon, the astronauts will reboard the Human Landing System and return to Gateway. Taking samples with them, they will return to Orion for the journey home.

9 SPLASHDOWN

After spending less than 30 days in space, the parachuted capsule will return to Earth, splashing down in the Pacific Ocean. NASA will have a team ready to retrieve the crew and the capsule.



MAIN MISSION OBJECTIVES

LONG-TERM PRESENCE

Following Apollo 17's three-day presence on the Moon, Artemis will send astronauts there for a few weeks.

EQUALITY

A female astronaut hasn't set foot on the Moon yet. This mission will demonstrate the increasing role women have played in space missions since the Apollo era.

PARTNERSHIPS

NASA has collaborated with private companies such as SpaceX and Boeing. These show space travel's shift towards commercialisation.

TECHNOLOGY

NASA is always learning from past missions; the spacecraft and spacesuits have been tailored to the Moon mission, exhibiting the latest in space technology.

KNOWLEDGE

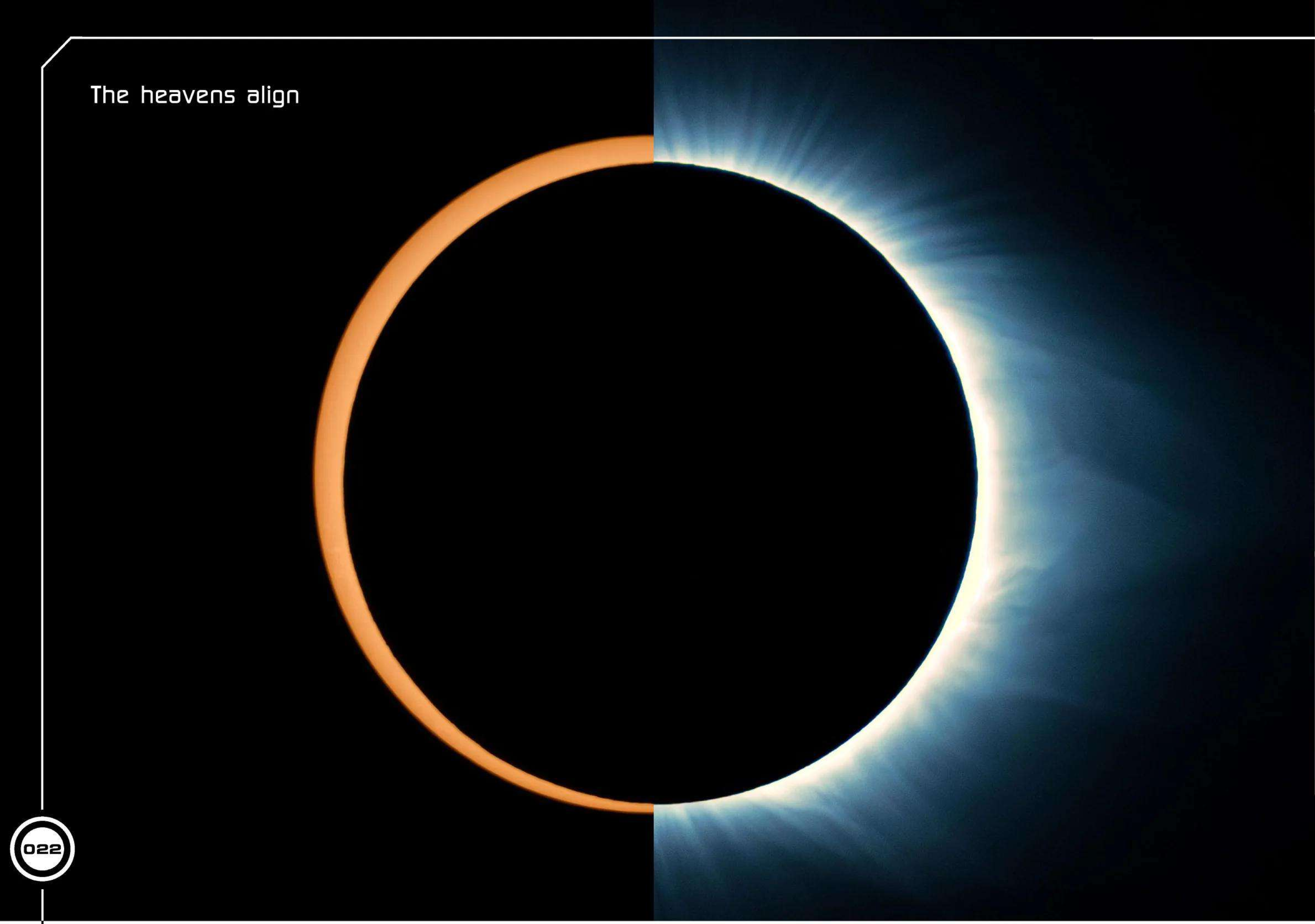
Collecting further information about the lunar surface and deep space, NASA hopes to become better prepared for later missions back to the Moon and further afield.

RESOURCES

Access to the lunar surface provides the opportunity to search for rare minerals and exploit resources. Hydrogen and oxygen could be used as rocket fuel to travel from the Moon.

THE CITY OF ANGELS

This stunning image traces the different phases of a solar eclipse over Los Angeles, California.



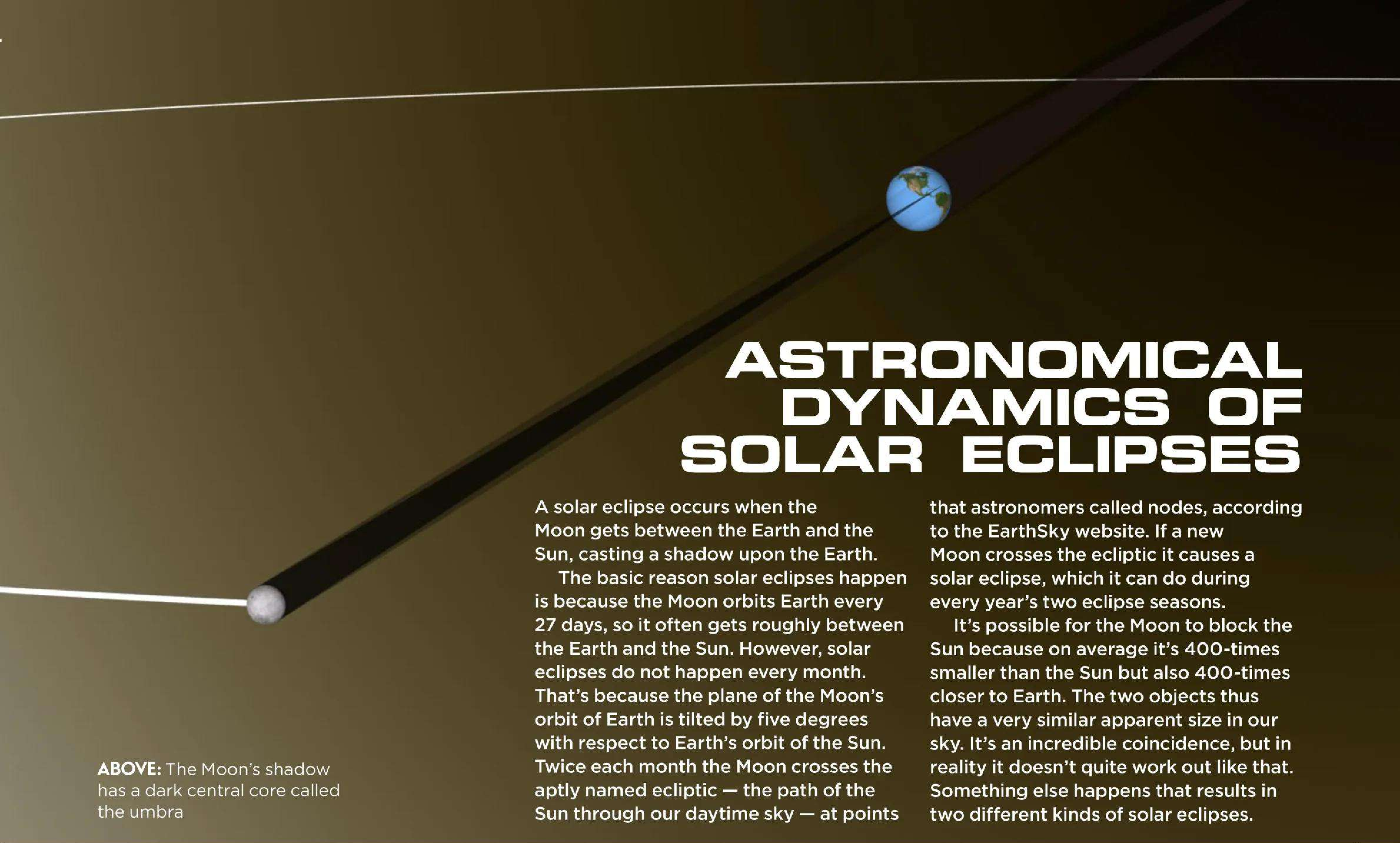
TYPES OF ECLIPSE

Have you always wondered what the difference between a total solar eclipse and an annular solar eclipse is? Well allow us to shine some light on the matter

WORDS JAMIE CARTER

Solar eclipses can be confusing. Almost everyone has heard of a total solar eclipse (also known as a total eclipse of the Sun), but it's often mixed up with a 'ring of fire' annular solar eclipse ('annular' means 'ring'). Both types of solar eclipses are described by astronomers as central solar eclipses, but the exact geometrical differences between them are slight. Even so, those differences have a huge effect on what observers see and feel. While one of the eclipse types can be described merely as a beautiful sight, the other is an awe-inspiring, multi-sensory experience.

Here's everything you need to know about the astronomical differences between a total solar eclipse and an annular solar eclipse to help you to better understand these remarkable events and — for our readers in the U.S. — prepare you for the upcoming total solar eclipse on 8 April of this year.



ABOVE: The Moon's shadow has a dark central core called the umbra

ASTRONOMICAL DYNAMICS OF SOLAR ECLIPSES

A solar eclipse occurs when the Moon gets between the Earth and the Sun, casting a shadow upon the Earth.

The basic reason solar eclipses happen is because the Moon orbits Earth every 27 days, so it often gets roughly between the Earth and the Sun. However, solar eclipses do not happen every month. That's because the plane of the Moon's orbit of Earth is tilted by five degrees with respect to Earth's orbit of the Sun. Twice each month the Moon crosses the aptly named ecliptic — the path of the Sun through our daytime sky — at points that astronomers called nodes, according to the EarthSky website. If a new Moon crosses the ecliptic it causes a solar eclipse, which it can do during every year's two eclipse seasons.

It's possible for the Moon to block the Sun because on average it's 400-times smaller than the Sun but also 400-times closer to Earth. The two objects thus have a very similar apparent size in our sky. It's an incredible coincidence, but in reality it doesn't quite work out like that. Something else happens that results in two different kinds of solar eclipses.

TOTAL VS. ANNULAR: THE MOON'S THREE SHADOWS

When the Moon blocks a part of the Sun as seen from Earth it casts a fuzzy shadow across a large part of our planet. This is the Moon's penumbral shadow, and if you stand within it and use solar eclipse safety glasses you can see a partial solar eclipse. However, the inner and darker part of the Moon's shadow is what causes so-called central solar eclipses — annular and total.

This inner shadow is narrow, cone-shaped and projected as a path across Earth in addition to (and within) the penumbra. That path moves across Earth's surface from west to east because the Moon orbits west to east. During a total solar eclipse the tip of that cone touches Earth and is called the umbra. It's also why eclipse chasers are sometimes called umbraphiles, according to The Smithsonian. Those in this path of totality below experience a brief darkness in the day.

During an annular solar eclipse, the umbral cone doesn't reach Earth and instead creates an antumbral shadow. Those in its path — the path of annularity — see a 'ring of fire' around the Moon.

"THIS INNER SHADOW IS NARROW, CONE-SHAPED AND PROJECTED AS A PATH ACROSS EARTH'S SURFACE IN ADDITION TO THE PENUMBRA"

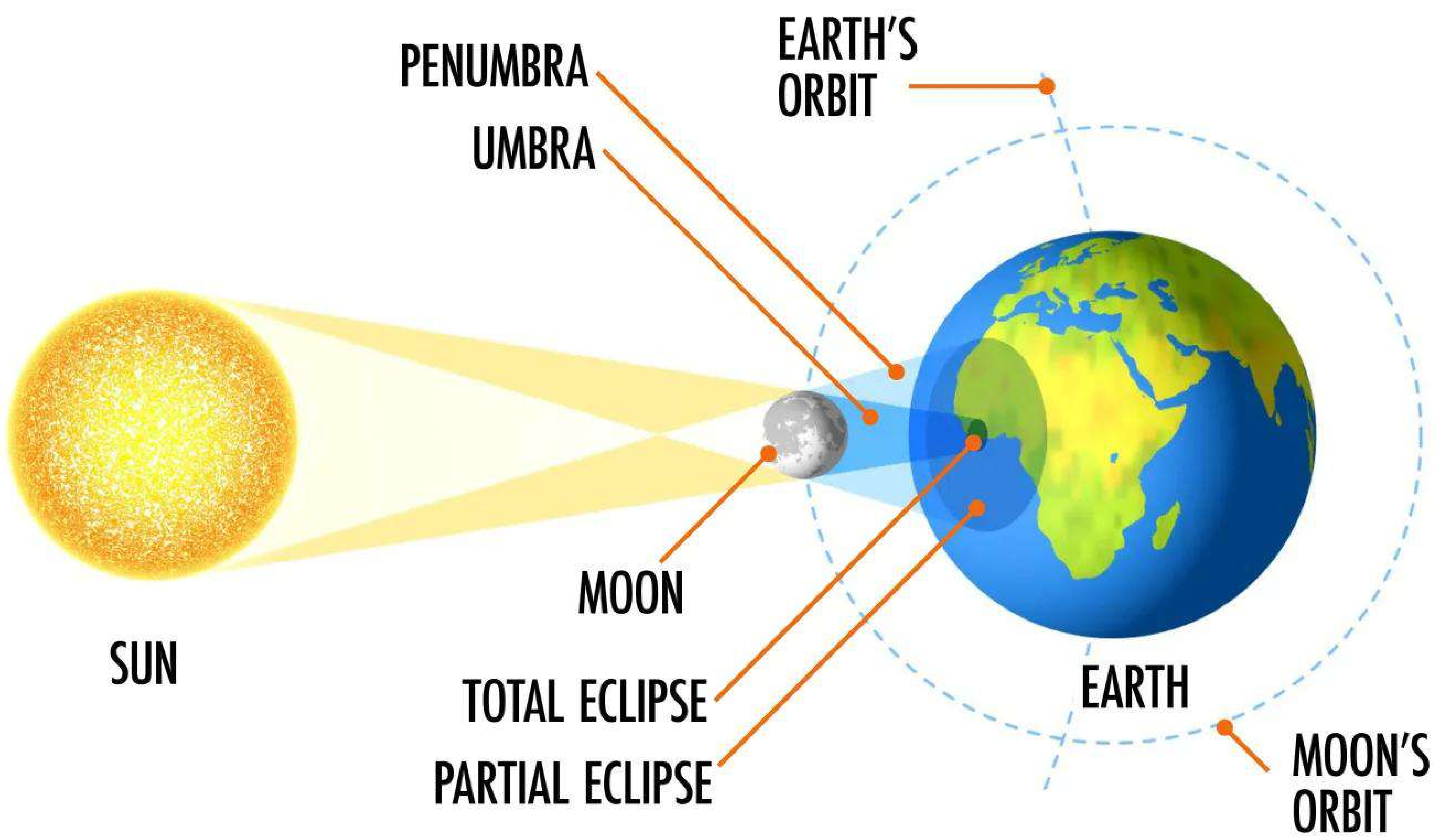
2017's total solar eclipse as seen from the International Space Station

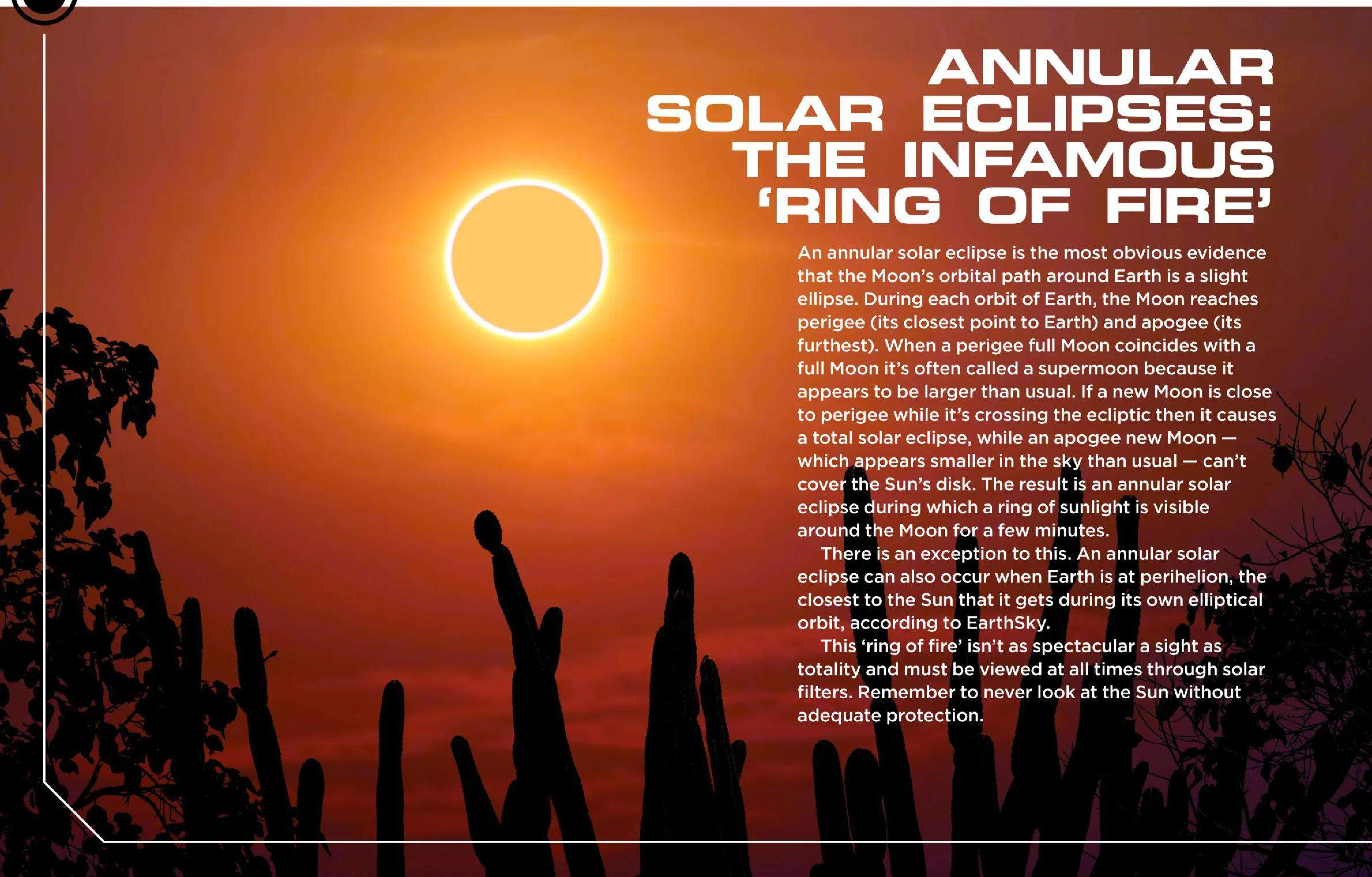
TOTAL SOLAR ECLIPSES: THE 'TOTALITY' PHENOMENON

A total solar eclipse occurs when the Moon passes precisely between Earth and the Sun while its apparent size is equal to, or bigger than, the Sun. Dedicated eclipse chasers aside, it's rare for anyone on Earth to experience a total solar eclipse. That's because you need to be on the day side of Earth during a solar eclipse but also within the path of totality (the Moon's umbral shadow), which is about 16,093 kilometres (10,000 miles) long but only about 161 kilometres (100 miles) wide. Besides, all solar eclipses largely occur at sea (over 70 per cent of Earth is covered by water).

The entire event takes about three hours, but it's the brief totality – when all of the Sun's light is blocked (for up to six minutes) — that's the reason eclipse chasers will go anywhere to experience one. Totality gives viewers a chance to see the Sun's outer atmosphere — the corona — with the naked eye, which is normally lost in the Sun's glare. On either side of totality, it's possible to see beads of light streaming through the valleys of the Moon. These are called Baily's beads.

The last Baily's bead before totality begins creates a 'diamond ring' effect for a split second as the corona emerges. The first Baily's bead as totality ceases causes another. Totality causes a deep twilight, with observers experiencing a noticeable drop in temperature approximately 20 minutes before totality because solar radiation in the umbra — the path of totality — is reduced.





ANNULAR SOLAR ECLIPSES: THE INFAMOUS 'RING OF FIRE'

An annular solar eclipse is the most obvious evidence that the Moon's orbital path around Earth is a slight ellipse. During each orbit of Earth, the Moon reaches perigee (its closest point to Earth) and apogee (its furthest). When a perigee full Moon coincides with a full Moon it's often called a supermoon because it appears to be larger than usual. If a new Moon is close to perigee while it's crossing the ecliptic then it causes a total solar eclipse, while an apogee new Moon — which appears smaller in the sky than usual — can't cover the Sun's disk. The result is an annular solar eclipse during which a ring of sunlight is visible around the Moon for a few minutes.

There is an exception to this. An annular solar eclipse can also occur when Earth is at perihelion, the closest to the Sun that it gets during its own elliptical orbit, according to EarthSky.

This 'ring of fire' isn't as spectacular a sight as totality and must be viewed at all times through solar filters. Remember to never look at the Sun without adequate protection.

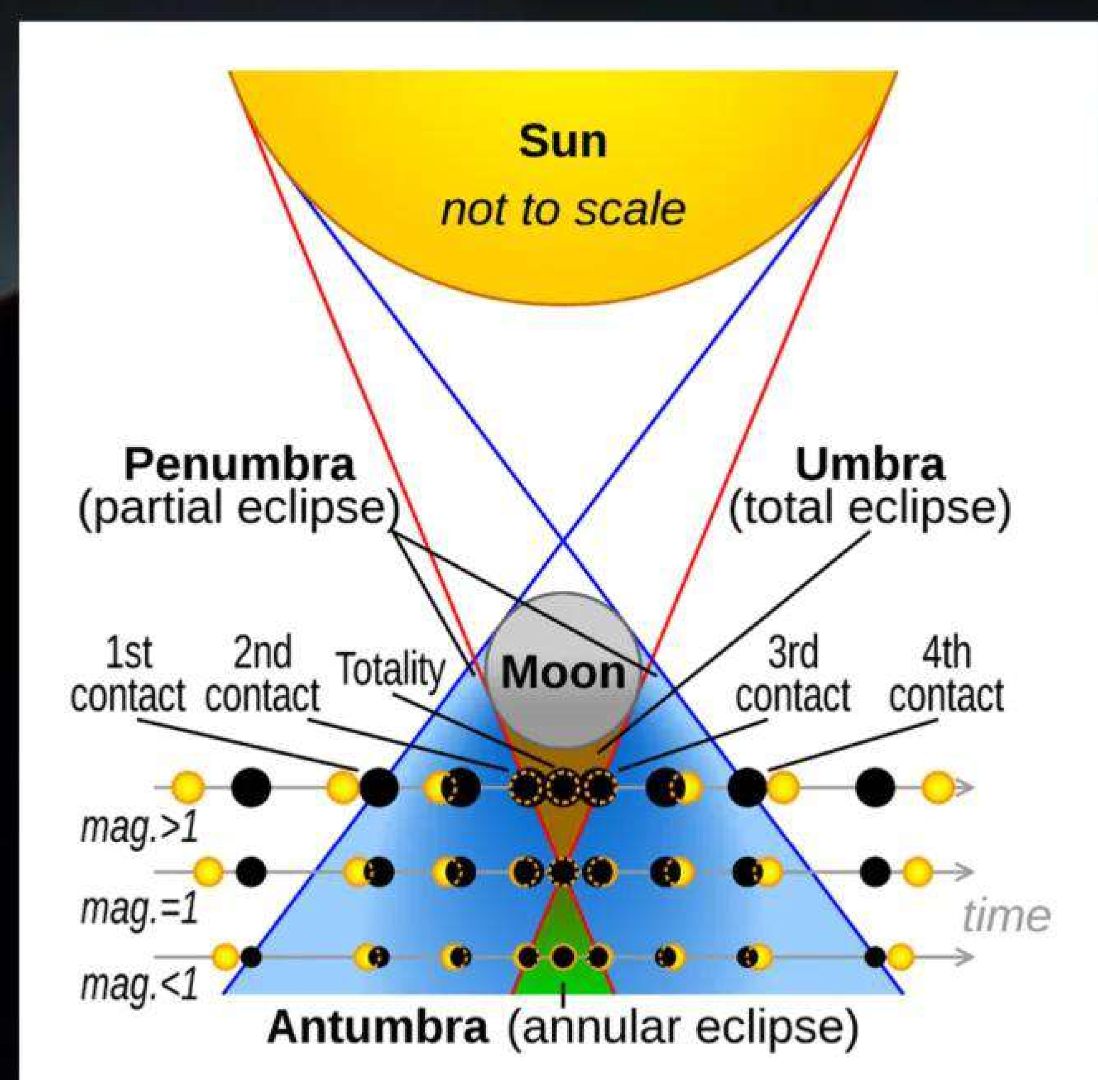
HYBRID SOLAR ECLIPSE: EVERYTHING YOU NEED TO KNOW

Hybrid solar eclipses occur just once every decade — and there's one coming in 2031

A hybrid solar eclipse combines an annular and a total solar eclipse where the former becomes the latter and then usually reverts back. Therefore, observers at different points in the eclipse path can experience different phenomena. For example, if you watch a hybrid solar eclipse at sunrise or at sunset you may see a brief 'ring of fire'. If you watch it at midday — so at the mid-point of the eclipse's path across the surface of Earth — you'll experience totality. It's therefore unfortunately impossible to experience both an annular and a total solar eclipse during a hybrid event; you have to make a choice.

WHY DO HYBRID SOLAR ECLIPSES OCCUR?

Hybrid solar eclipses occur when the Moon's distance is close enough to its limit for the umbral shadow to reach Earth and because Earth is curved. The Moon is just at the right distance from Earth for the apex of its cone-shaped shadow to be slightly above the Earth's surface at the beginning and end of the eclipse path, causing the Moon's antumbral shadow to move across Earth, thereby causing an annular solar eclipse. However, in the middle of the eclipse path the apex of the Moon's umbral shadow strikes Earth's surface because that part of the planet is slightly closer to the Moon.



Each of the three types of solar eclipse is caused by the Moon blocking light from different parts of the Sun.

The diagram below is of a hybrid solar eclipse and shows how the Moon's distance from the Earth determines the shadow projected onto the Earth's surface, from the faint penumbra of a partial solar eclipse to the deep, dark umbra of totality and the antumbra — a kind of half-shadow — of annularity.

WHEN IS THE NEXT HYBRID SOLAR ECLIPSE?

The next hybrid solar eclipse will occur on Friday, 14 November, 2031, according to Time and Date. At least a partial eclipse will be visible across parts of North America, South America, the Pacific and the Atlantic.

There will then be a bit of a wait until the following hybrid eclipses, which will occur on 25 November 2049 and 20 May 2050 respectively, meaning an 18-year wait and then two within six months!

The Baily's beads effect is seen as the Moon makes its final move over the Sun

15 FACTS YOU NEVER KNEW ABOUT ECLIPSES

Eclipses are one of nature's most amazing spectacles, and here are a few things you (probably) didn't know about them

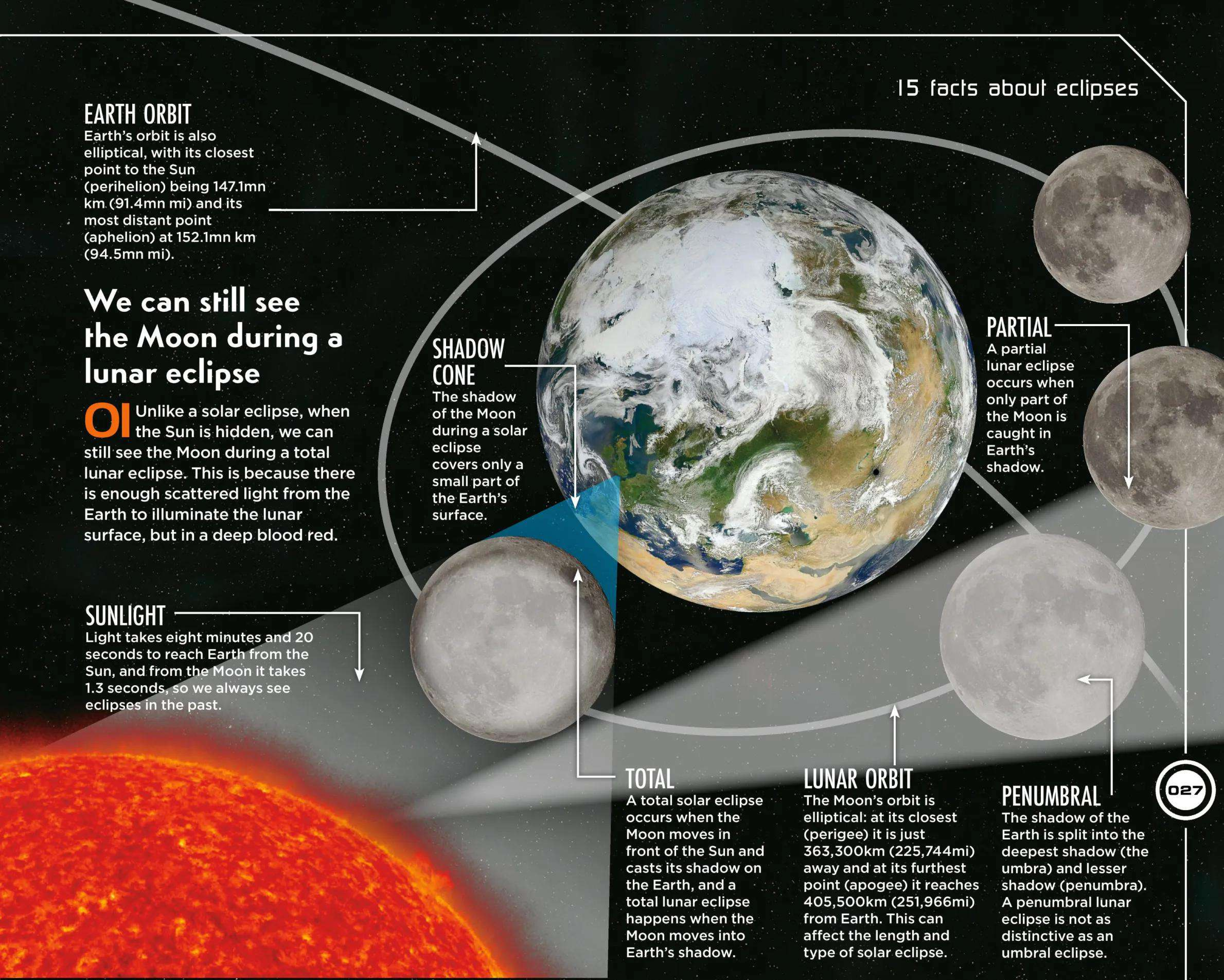
Have you ever seen the sky turn pitch black during the day? We don't mean the grey dark of a rainy day, but dark like the night. The only time you will ever see this is during a total solar eclipse, which is one of nature's most breathtaking eclipses. It happens when the Moon moves in front of the Sun, blocking its light, and underneath the Moon's shadow darkness falls.

Total solar eclipses are rare, and in a way it is an incredible stroke of luck that we have them. The Sun's distance from Earth just happens to be about 400 times the Moon's distance from our planet. The Sun also happens to be about 400 times larger than the Moon, so thanks to this magic ratio they appear about the same size in the sky, meaning that during an eclipse the Moon can fit precisely over the Sun. We have to say 'about' a lot because Earth's orbit and the Moon's orbit are not circular but elliptical, meaning sometimes they can be a bit further away, or a bit nearer. This results in the Sun sometimes appearing larger than the Moon during some eclipses, leaving a ring of light from the Sun around the Moon's silhouette. We call this an annular eclipse.

An eclipse begins at 'first contact' when the Moon's disc first touches the Sun's disc. You won't notice a change in the light at this point — in fact it won't get dark until the Moon has practically covered all of the disc. This is called second contact, when the far limb of the Moon's disc touches the Sun's apparent disc. Totality, which is how we describe the Sun being blocked by the Moon, can last for several minutes.

Third contact happens when totality ends and the Moon begins to move away from the Sun and daylight returns once more. Fourth contact is when the Moon moves completely off the Sun and the eclipse ends.

The Moon is very slowly moving away from Earth at a rate of 3.8 centimetres (1.5 inches) per year, so eventually it will appear too small to completely cover the Sun. Luckily, this day won't arrive for at least another 500 million years.



We can still see the Moon during a lunar eclipse

01 Unlike a solar eclipse, when the Sun is hidden, we can still see the Moon during a total lunar eclipse. This is because there is enough scattered light from the Earth to illuminate the lunar surface, but in a deep blood red.

The length of totality can vary

02 Some eclipses are very short, with totality lasting just a couple of minutes. Others can last six or seven minutes. The reason for the difference is a result of the elliptical orbits of Earth and the Moon. When the Moon is closer to Earth in its orbit it moves faster. The same applies to the Earth around the Sun, and this all affects the speed at which we see the Moon move across the Sun during a solar eclipse.

You can see the Sun's atmosphere

03 The Sun has an atmosphere, split into two parts. The lower part is called the chromosphere, where the temperature rises from 6,000 to 20,000 degrees Celsius (10,832 to 36,032 degrees Fahrenheit). The upper part is called the corona and can reach temperatures in excess of 1 million degrees Celsius (1.8 million degrees Fahrenheit). During totality you can see this corona as flares of light around the hidden Sun. You might also catch a glimpse of the chromosphere as a red tinge at the edge of the Moon at third contact.

You can see the planets during an eclipse

04 If you are lucky enough to see a total solar eclipse, take a few moments to also glance around the sky. In the darkness the stars and planets will pop out. Closest to the Sun will be Venus and Mercury, but you could also see other planets depending where in the sky they are at the time.

UK solar eclipses are rare

05 Total solar eclipses seen from the UK are very rare. The last one was in 1999 and the next won't be until 23 September 2090, where Cornwall will be in the umbral shadow for two minutes and ten seconds. However, there will be partial solar eclipses visible in 2026 on the islands of Shetland and Orkney and along the northern coast of Scotland.

Solar eclipse hunters will need a passport

06 There are plenty of opportunities to view a solar eclipse over the next ten years if you are willing to travel. The next total solar eclipse after the upcoming event on 8 April 2024 (visible in the U.S., Canada and Mexico) will occur on 12 August 2026, when Greenland, Iceland, Portugal, Spain and Russia will witness a total eclipse while a partial eclipse will be viewable in over 70 other locations.

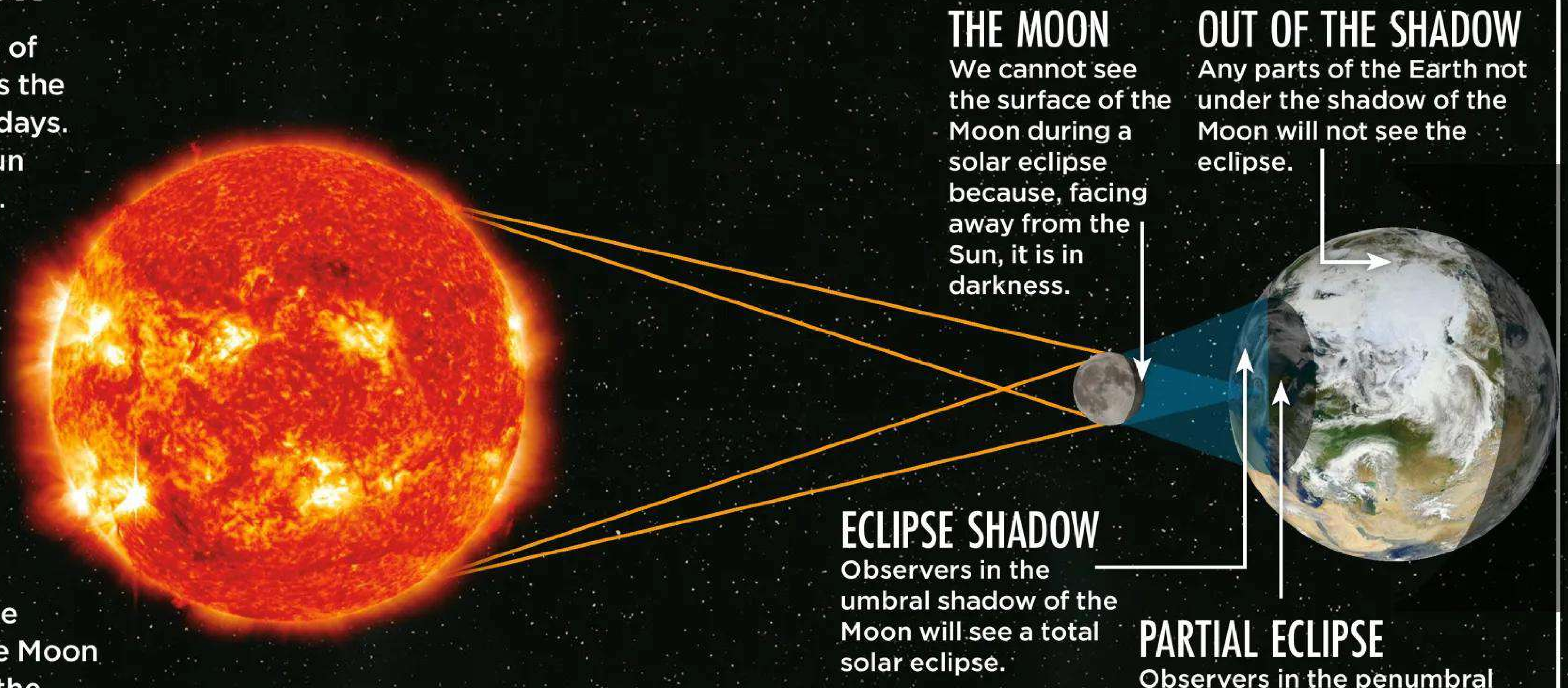
They can create diamond rings

07 Just at the moment totality begins or ends a spectacular effect takes place that is called the 'diamond ring'. When this happens a bright burst of light appears that looks very much like the jewel in a diamond ring. This is caused by sunlight bursting through gaps between mountains on the edge of the Moon.

HOW A SOLAR ECLIPSE FORMS

A solar eclipse is a consequence of an alignment of the Earth, Moon and Sun

Eclipses are all a result of orbits. The Moon orbits the Earth once every 27.3 days. The Earth orbits the Sun once every 365.2 days. Their orbits are elliptical, meaning their distance from their parent body can change throughout an orbit. The tilt of the Moon's orbit relative to the ecliptic (the path of the Sun through the sky) is 5.1 degrees. A solar eclipse happens only when the Moon crosses the ecliptic at the exact position that the Sun is in at that moment in time.



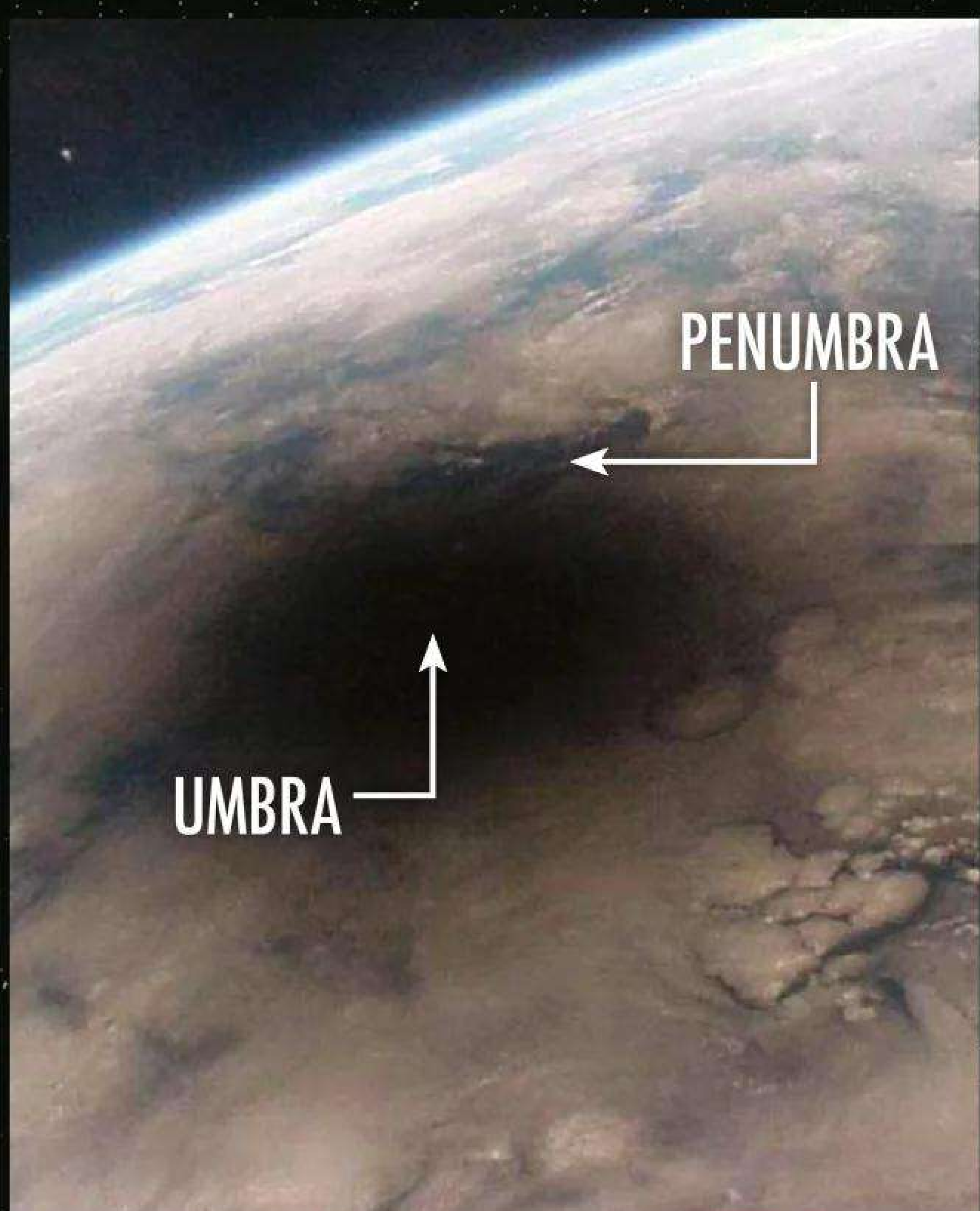
Solar and lunar eclipses come in pairs

08 There is always a lunar eclipse either two weeks before or two weeks after a solar eclipse. This is because the alignment between the Sun, Moon and Earth is still close enough that, a fortnight before or after a solar eclipse, when the Moon is on the other side of the Earth, the Moon can fall into Earth's shadow.

The characteristic reddish hue of a lunar eclipse will often appear not long before or after a solar eclipse

The Moon's shadow moves very fast

09 The Moon's shadow moves across the Earth from west to east faster than the speed of sound, with the eclipse shadow at the equator travelling at 1,730 kilometres (1,075 miles) per hour. This is because the Moon is orbiting Earth at 3,400 kilometres (2,113 miles) per hour, counterbalanced by the Earth's rotation at 1,670 kilometres (1,038 miles) per hour. This is also why the Moon moves across the sky faster than the Sun.



There is more than one type of shadow

10 A shadow is divided into two parts — the umbra and the penumbra. The umbra is the central, deepest part of the shadow. The penumbra is where only part of the source of light is blocked. Total eclipses are seen in the umbra, while partial eclipses are seen in the penumbra.

They require syzygy

11 Eclipses occur during a particular alignment of the Sun, Moon and Earth called syzygy (pronounced siz-uh-jee).

Ancient eclipses

12 In the past, total solar eclipses were often interpreted as portents of doom, which could in turn prompt a period of unrest or even conflict. The Battle of the Eclipse — which was fought in 585 BCE between the kingdom of Lydia in Asia Minor and the Medes of what is today Iran — ended in a draw after an eclipse interrupted the bloodshed.

The UK has a while to wait for its next one

13 Lunar eclipses are much more common than solar eclipses, occurring twice a year in different parts of the world. The next total lunar eclipse visible from the UK will be on 7 September 2025, while the next total solar eclipse observable in the UK won't be until 23 September 2090!

Eclipses are relatively rare

14 On average, total solar eclipses happen every 18 months, although sometimes it can be several years between eclipses. They don't occur every month because the Moon's orbit is tilted with respect to the Earth's orbit around the Sun, so it is therefore only rarely that the Moon's path across the sky intersects with the Sun's.

THEY MUST BE OBSERVED WITH CARE

15 It is very dangerous to look directly at the Sun without using special eclipse glasses or a telescope with a specialist solar filter. This is because the Sun is so bright it can damage your eyesight or even blind you. Even if 99 per cent of the Sun's surface is blocked by the Moon, the remaining light can still burn your retina. Here are some safe ways to observe the Sun and eclipses:

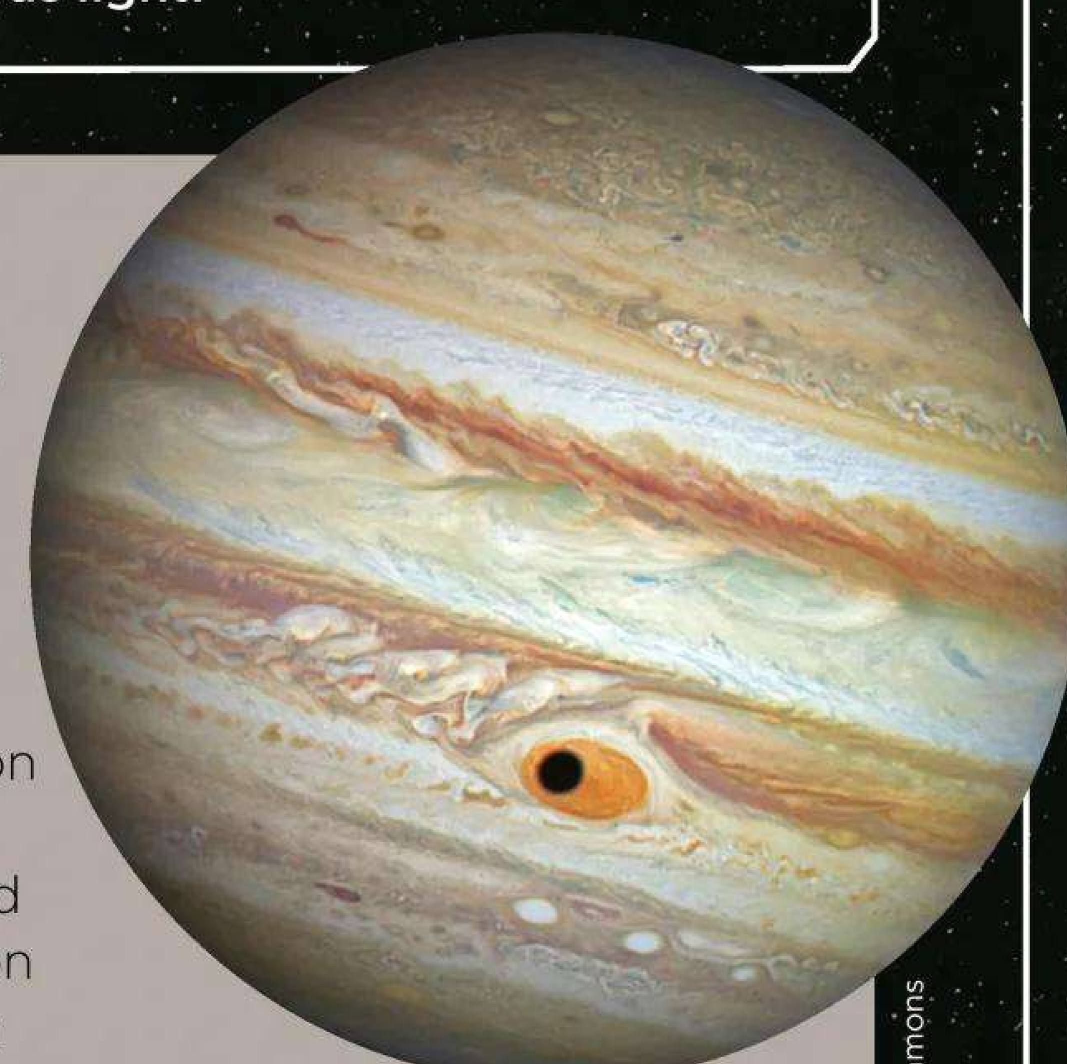
1. If using eclipse glasses, check they do not have any damage. Even a pinhole could damage your eyesight.

2. Try projecting the image of the Sun through a telescope onto a piece of white card. Keep the finderscope covered in case children accidentally look through it.

3. You can also use specialist solar filters and telescopes. These can be a bit expensive but they allow you to view the Sun at other wavelengths of light, such as hydrogen-alpha, which appears orange, blocking out the dangerous light.

Eclipses on other planets

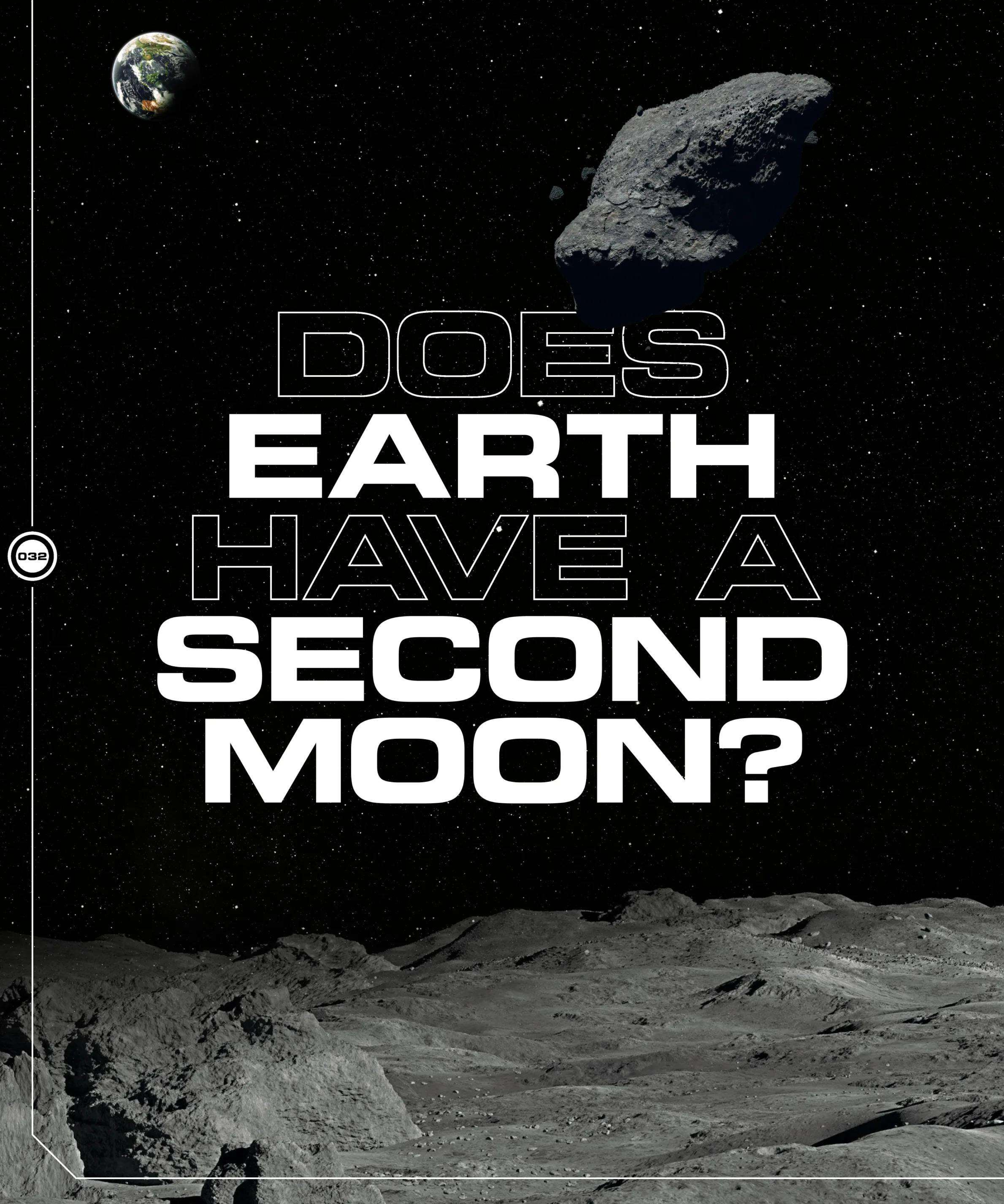
Solar eclipses do occur on other planets and moons in our solar system, but because they do not have the size ratio that we have between the Earth and our Moon, their eclipses are not as spectacular. Mercury and Venus cannot have eclipses because they do not have any moons. Mars' two moons are too small to totally obscure the Sun, but the rovers on the Red Planet have photographed Phobos (the larger of the pair) moving in front of the Sun in a kind of partial eclipse. We can see eclipses taking place on Jupiter with our back-garden telescopes in the form of the shadows of its four major moons cast on the uppermost cloud layer of the giant planet. Astronomers call these 'shadow transits' and several can happen at once. We can also see Jupiter's moons go into eclipse in the shadow of Jupiter. Similar eclipses can take place on all of the giant planets of the outer solar system, even on the dwarf planet Pluto, where its largest moon, Charon, can eclipse the distant Sun a couple of times each century.



The shadow of the Jovian moon Ganymede can be seen transiting across the surface of gas giant Jupiter

DIAMOND IN THE SKY

Captured over New Caledonia (an island in the South Pacific) on 13 November 2012, this total solar eclipse displays the striking 'diamond ring' effect.



DOES EARTH HAVE A SECOND MOON?

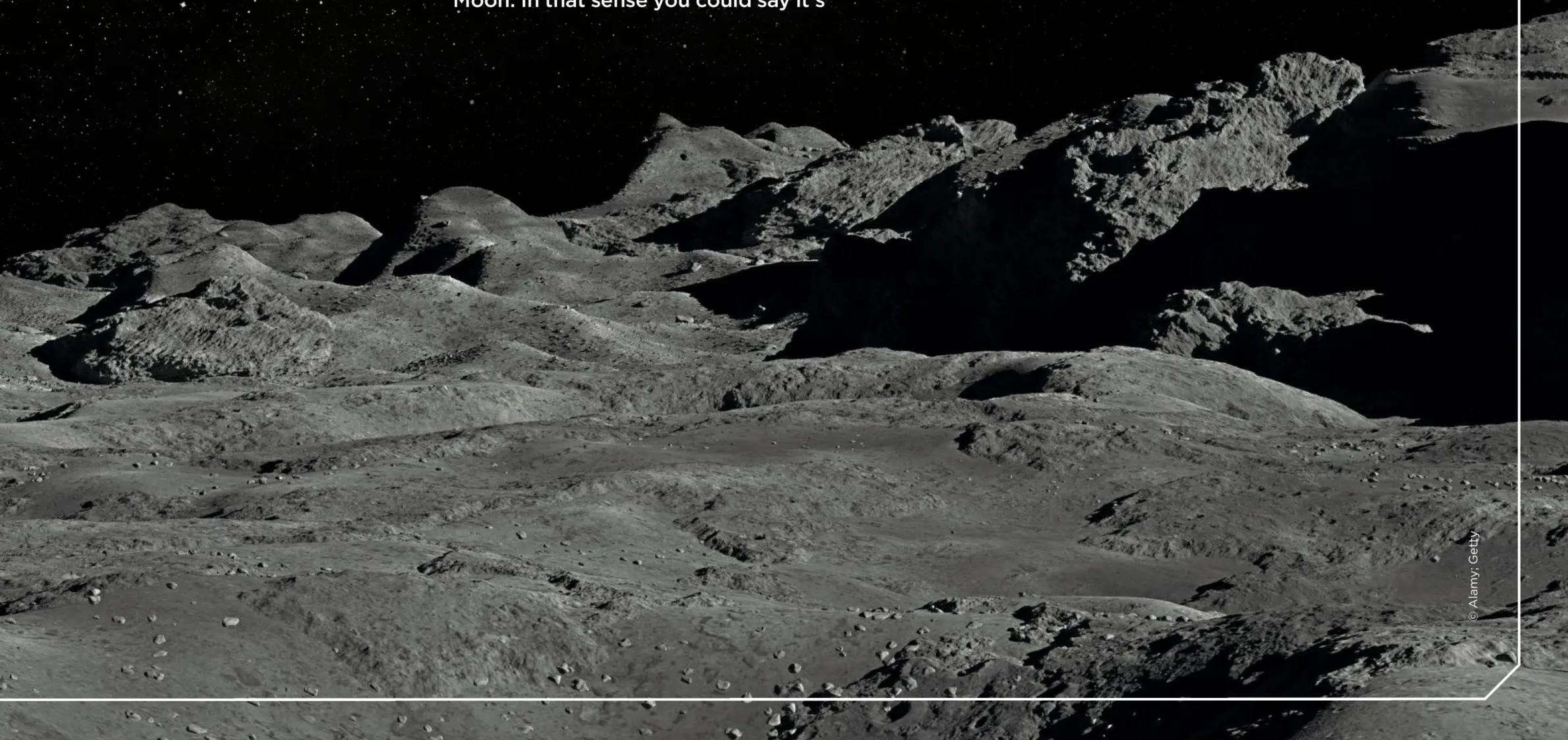
There's an asteroid tracking our planet's orbit around the Sun, and astronomers have been surprised by its composition

WORDS DAVID CROOKES

We all know that Earth only has one moon, and if you want proof of that, you just need to peer at the night sky. Can you see another? Astronomers are sticking to their guns by saying the Moon is Earth's only natural satellite. Case closed — or so you'd think.

In 2016, however, astronomers using the asteroid-hunting Pan-STARRS telescope in Hawaii discovered a rock orbiting the Sun while also repeatedly looping around Earth. Celestial objects such as these are called quasi-satellites, and while four others have been identified since 2004, this one was the closest and most stable ever seen.

What makes it particularly interesting is its potential origin, although a recent breakthrough has gone a long way towards clearing up the mystery over what this object could be. The smart money is now on it actually being a fragment of our Moon. In that sense you could say it's



© Alamy; Getty

KAMOʻOALEWA BY NUMBERS

9 MILLION
The closest Kamoʻoalewa gets to Earth, in miles

25 MILLION
The furthest Kamoʻoalewa gets from Earth, in miles

365.9
Orbital period, in days

2016
Year it was discovered

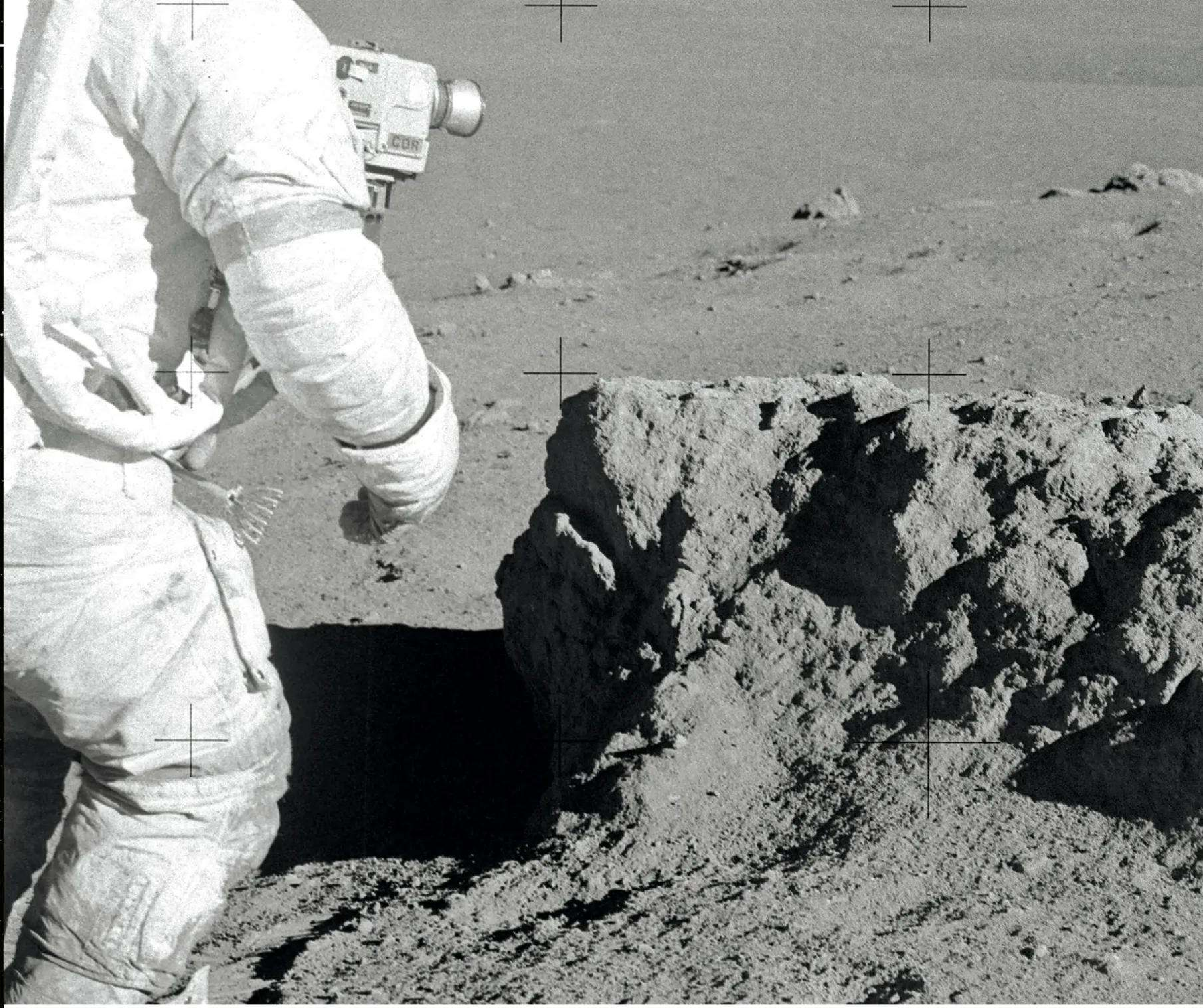
45 TO 58 METRES
The estimated size of Kamoʻoalewa (148–190ft)

30
Kamoʻoalewa's rotational period, in minutes

NINE
Number of asteroids found to have lunar origins

4 MILLION
times fainter than the faintest star visible with the naked eye

500 TO 100,000
Years ago it may have broken off the Moon



ABOVE: Rock samples collected from the Moon during the Apollo 14 mission compared almost perfectly to the data gathered about Kamoʻoalewa

Earth's second moon — as some have indeed dubbed it — though it's not quite on that level, if truth be told. Still, it's no less intriguing, and astronomers are keen to discover more.

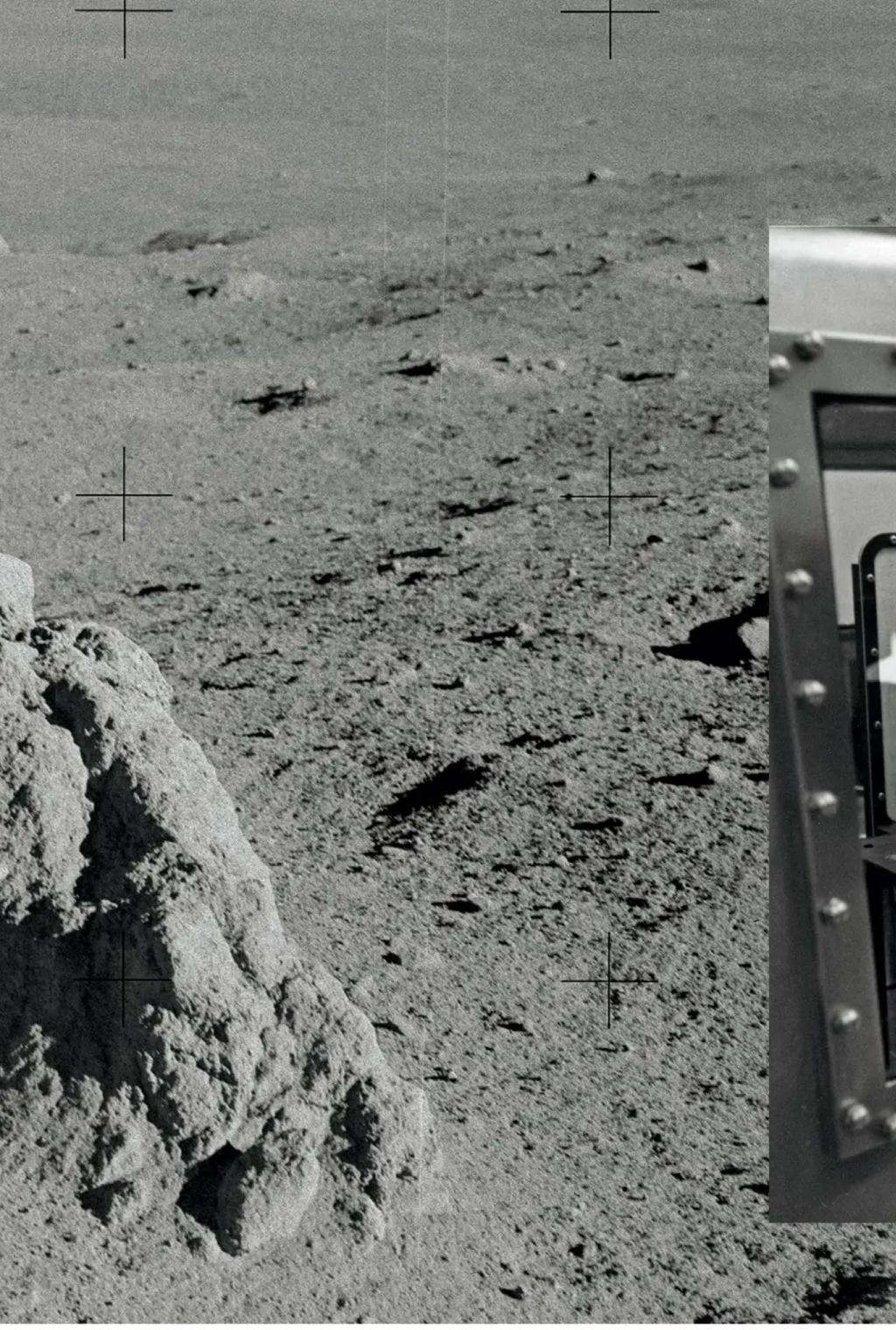
One of the people leading studies into the object, which is called Kamoʻoalewa (a Hawaiian name that roughly means 'oscillating celestial fragment'), is University of Arizona planetary sciences graduate student Ben Sharkey. In the years since its discovery he has dedicated much of his time and energy to unearthing the origin of the celestial body, with interest piquing following the publication of his team's academic paper in the scientific journal *Communications Earth & Environment*.

Getting this far has certainly been no easy task. The eccentric entity is no more than 58 metres (190 feet) in diameter, which makes it roughly the size of a Ferris wheel. What's more, the orbiting object is 4-million-times fainter than any human could see with the naked eye and about 40-times further out than the Moon. At its greatest distance it is 40.2 million kilometres (25 million miles) away, and it gets no closer to Earth than 14.5 million kilometres (approximately 9 million miles). But there it is, in orbit around Earth and the Sun, albeit following a rather strange path.

"Kamoʻoalewa is kind of weaving inside and outside of Earth's orbit as both it and our planet go around the Sun," Sharkey explains, this behaviour resulting from the Sun and Earth's gravitational pulls competing with one another. "If you look at that from the perspective of Earth, it looks like a cork scurrying around the planet in an orbit that doesn't close at any point. It never repeats the same loop in exactly the same way."

The celestial object's odd corkscrew-like orbit certainly caught astronomers' imagination. "We could tell this object had a unique orbit, so there was an immediate interest in characterising it to determine what it's made of and how it is spinning," Sharkey says. "As a student, it seemed like a challenging and interesting project to sink some time into, so we collected a bunch of different kinds of data over a long period of time." Such diligence has reaped rewards.

There's no doubt that the Arizona study has progressed slowly, but there's been no way of speeding it up. It's only been possible to observe Kamoʻoalewa for a few weeks every April, when it is illuminated by the Sun, but astronomers have nevertheless been able to study the object sufficiently to draw some conclusions. They have been primarily making use of the Large Binocular



LEFT: Moon rock samples brought back in the Apollo era have told us much about our lunar companion

BELOW: 'Big Bertha', the third-largest lunar sample ever collected

"KAMO'OALEWA IS KIND OF WEAVING INSIDE AND OUTSIDE OF EARTH'S ORBIT AS BOTH IT AND OUR PLANET GO AROUND THE SUN"

BEN SHARKEY

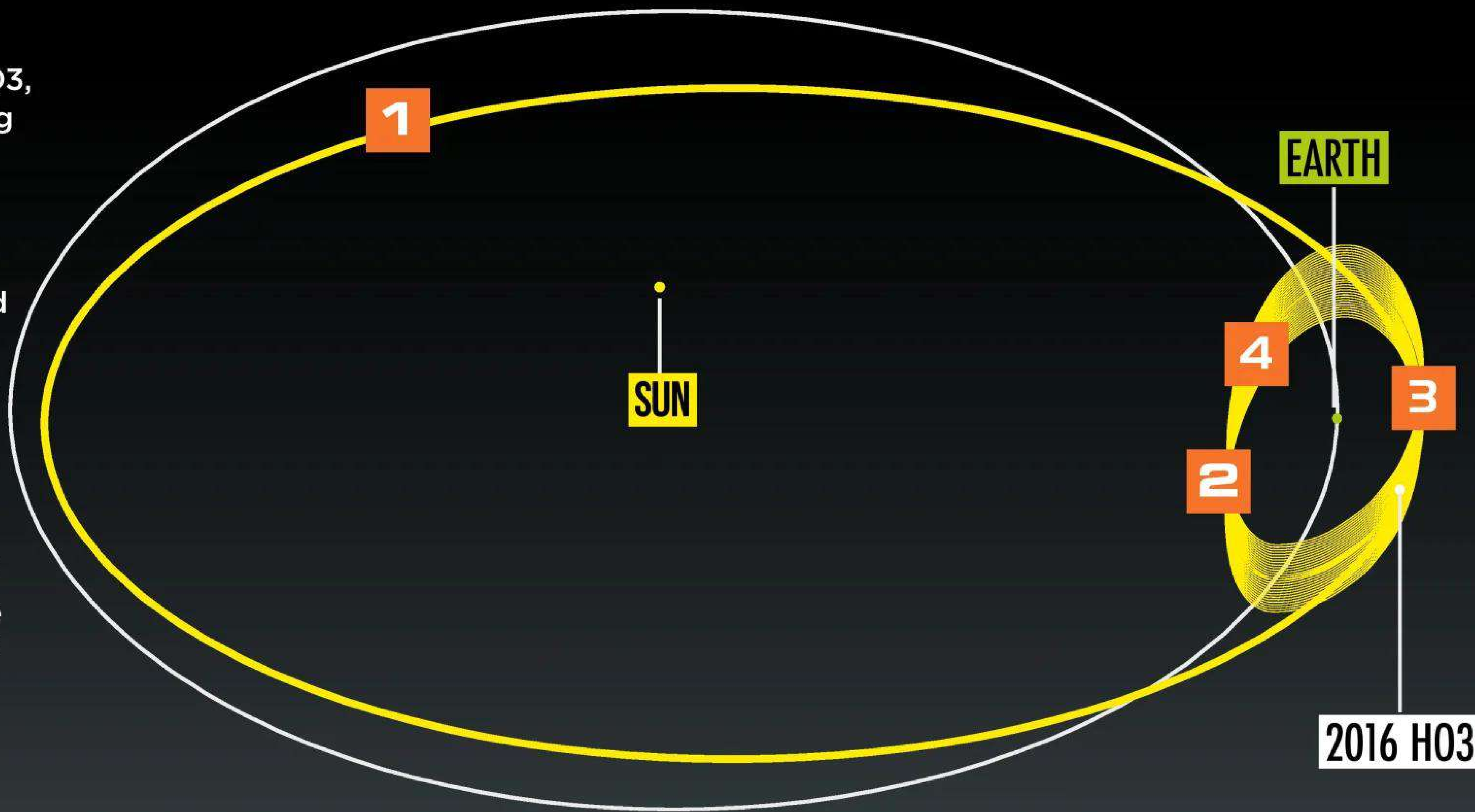
Telescope on Mount Graham in southern Arizona. The observatory's huge nine-metre (28-foot) mirrors allowed a much closer look at Kamo'oalewa, with observations beginning in 2017.

Backed by data from the Lowell Discovery Telescope, which is a five-hour drive away in Flagstaff and funded by NASA's Near-Earth Object Observations Program, the astronomers have been able to monitor Kamo'oalewa's faint infrared signature. The team would make observations then plan ahead for the following year's window of opportunity, building up a solid bank of knowledge.

"Asteroids like this are essentially darker than the sky and fainter than the background glow, so you need large

PLOTTING KAMO'OALEWA'S ORBIT

How the asteroid became Earth's moon-like buddy



1 ORBITING THE SUN
Kamoʻoalewa is also known as 2016 HO3, and just like Earth it orbits the Sun, taking just over a year to do so.

2 STAYING CLOSE
Kamoʻoalewa also circles Earth, and it has become a stable quasi-satellite. It doesn't venture too far away as both the asteroid and Earth orbit the Sun.

3 WEAVING IN AND OUT
The asteroid spends roughly half of the time closer to the Sun than Earth; the objects leapfrog so that the other half of the time it is further away.

4 GRAVITATIONAL PULL
This unusual orbit is due to Earth's gravity being strong enough to hold onto the asteroid. It doesn't venture further than 100 times the distance of Earth to the Moon.

Pan-STARRS is the world's leading near-Earth object discovery telescope. It picked up on Kamoʻoalewa in 2016

telescopes and infrared instruments to make these detections," Sharkey explains.

Slowly but surely, the team's observations and analyses pointed them towards Kamoʻoalewa being a lost piece of the Moon.

There's a big reason why this is a major deal. If Kamoʻoalewa is indeed a lunar fragment then it would be the only known asteroid with a lunar origin. It also opens up a whole new line of inquiry that explores how the piece came to break away and when it happened. Of course, such events have occurred many times in the past.

"You can see craters on the Moon with your own eyes," explains Sharkey. But we think of most asteroids as coming from the asteroid belt.

"We know material from the Moon has been ejected in the past, some of it coming to Earth as meteorites," Sharkey says. "Hundreds of lunar meteorites have been collected on Earth, so impacts on the Moon are not uncommon. But the question is whether we can find a link in the processes. Is there a possibility that material from the Moon that hasn't hit Earth is out there, yet to be found? We could tell a lot about how material has mixed or moved around the Solar System with time."

Sharkey and his team knew early on that Kamoʻoalewa wasn't a standard near-Earth asteroid. During observations it wasn't reflecting brightly in particular infrared frequencies, even though it was made of common silicates in the same way as other asteroids. Sharkey sought to match data gathered on Kamoʻoalewa with the light reflecting off other near-Earth asteroids. But Kamoʻoalewa's dimmer reflection pointed to it being composed of a different material. Researchers just needed to be totally sure there had not been a mistake.

"The spectral signature of some other asteroids can actually look very similar to what Kamoʻoalewa looks like at visible wavelengths," Sharkey says. "We had this expectation that it would basically reflect infrared light in a similar way to how it did in the visible, but it displayed a redder reflectance spectrum. We tried to run through different scenarios and think about the different ways to change how asteroids reflect light. This doesn't have to do with just the material it's made of. It could be to do with different textures of the surface; scuffing can make something appear darker or change its colour, for instance, altering how asteroids are reflecting light.

"But we tried to say if we take a more typical asteroid and apply this effect, can we come up with a satisfying answer and achieve a reflection identical to what we saw with Kamoʻoalewa? And our argument was that we can't get anything else to work.

Denise Hung and Dave Tholan of the University of Hawaii took this image of Kamoʻoalewa on 10 June 2016

© EarthSky

"WE COULD TELL THIS OBJECT HAD A UNIQUE ORBIT, SO THERE WAS AN IMMEDIATE INTEREST IN CHARACTERISING IT"

BEN SHARKEY

Then we saw that there's a source of material that has a very good match to this spectrum which is nearby: space-weathered lunar silicates."

It opened up a winning line of inquiry. As luck would have it, one of Sharkey's PhD advisors had studied samples collected from the Fra Mauro formation in the lunar highlands that had been brought back to Earth by the Apollo 14 mission in 1971.

"It was a kind of funny moment because he just sort of mentioned it randomly, and it was like, 'Hey, you should probably think about this comparison too'," Sharkey says.

By comparing Kamoʻoalewa's pattern of reflected light to those lunar samples, a near-perfect match was found. This suggested that Kamoʻoalewa indeed originated from the Moon, with the spectral characteristics being consistent with silicate material showing a high degree of space weathering, such as solar wind particles or micrometeorite bombardment.

Even so, Sharkey and his advisor, University of Arizona associate professor of lunar and planetary sciences Vishnu Reddy, harboured doubts. Although a second set of data was obtained in 2019, they were frustrated that they couldn't observe Kamoʻoalewa in 2020 because the COVID-19 pandemic caused the Large Binocular Telescope to be shut down. Fortunately, it was back up and running in

THE THEORIES

Astronomers have considered a few explanations for Kamoʻoalewa's origin

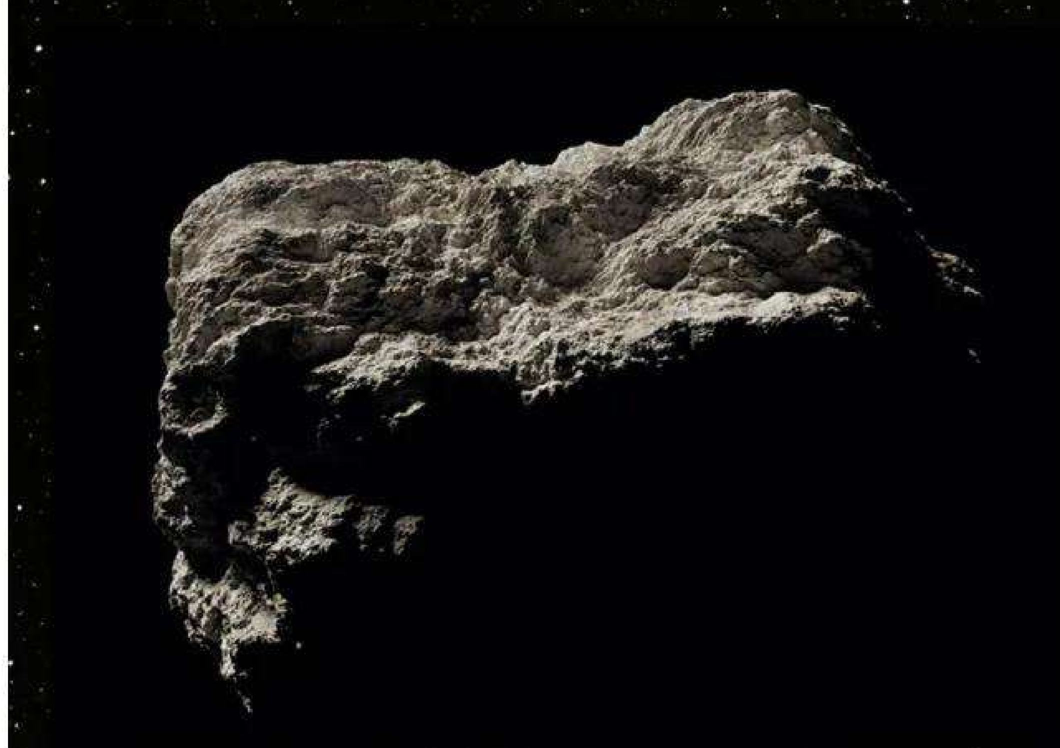
A CAPTURED ASTEROID

The study's authors examined the possibility that Kamoʻoalewa was captured in its Earth-like orbit from the general population of near-Earth objects. But the paper says that simulations of such a scenario don't match the low eccentricity and inclination displayed by Kamoʻoalewa.

© Getty

FRAGMENT OF AN ASTEROID

There are two known asteroids that orbit the Sun at the Earth-Sun Lagrangian points L4 and L5. They have similar orbits to Earth's, and it could be that Kamoʻoalewa is a splintered piece of one of them.



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A PIECE OF THE MOON

The study strongly suggests that the asteroid is an ejected fragment of the Moon, probably caused by an impact. This is supported by the reflectance spectrum of Kamoʻoalewa being a near-perfect match in comparison to rock samples returned from the Moon.

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"IT WILL NOT REMAIN IN THIS PARTICULAR ORBIT FOR VERY LONG, ONLY ABOUT 300 YEARS IN THE FUTURE; IT ARRIVED IN THIS ORBIT ABOUT 500 YEARS AGO"

RENU MALHORTA

April 2021, allowing another observation, and this finally convinced the team that they were correct.

But Kamoʻoalewa isn't going to hang around. According to the study's co-author, University of Arizona planetary sciences professor Renu Malhorta, who has been studying the orbit, it will wave goodbye in about 300 years time once it frees itself from the gravitational ropes that are keeping it around Earth.

"It will not remain in this particular orbit for very long, only about 300 years in the future," Malhorta affirms, adding that "it arrived in this orbit about 500 years ago".

But what exact path it will take when it goes on its lonely adventure is not entirely certain. What we do know, however, is that it's gravitationally bound to the Sun rather than Earth, and that's why it can't actually be classed as a moon, even though it's made up of a bit of one.

"Orbital dynamics are outside my normal expertise," says Sharkey, "but one of the big challenges is tracing the exact path of an object like this beyond a few hundred years. Your uncertainties just become so large that it's really difficult to say anything with confidence besides the sort of general ideas about the state of the object. Beyond 300 years or so, it's a question of the exact path it takes, but it's not going to shoot off in some new direction. It's going to be a more gentle progression than that."

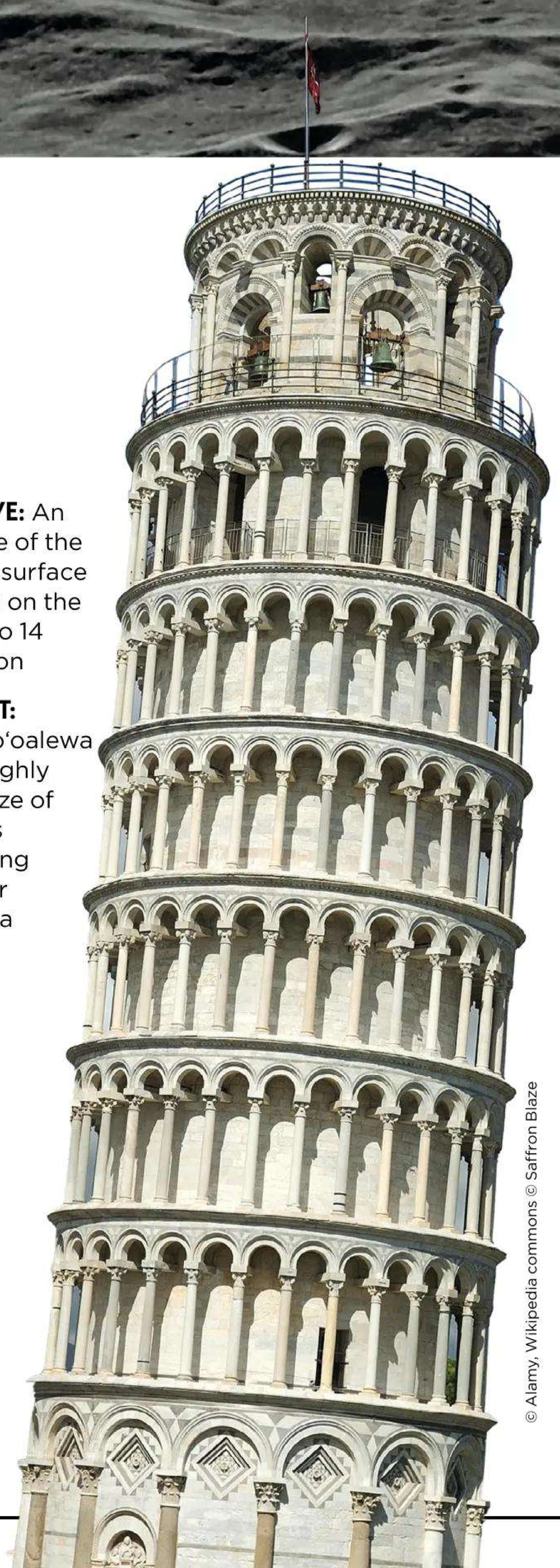
This still gives plenty of time to make more observations, and while there's no chance anyone is going to be thinking of landing a human on this particular 'moon', a sample-return mission to Kamoʻoalewa is being planned by the China National Space Administration, with a launch pencilled in for 2025. It's also possible that Kamoʻoalewa is not alone, and the orbits of three other near-Earth objects could even be linked.

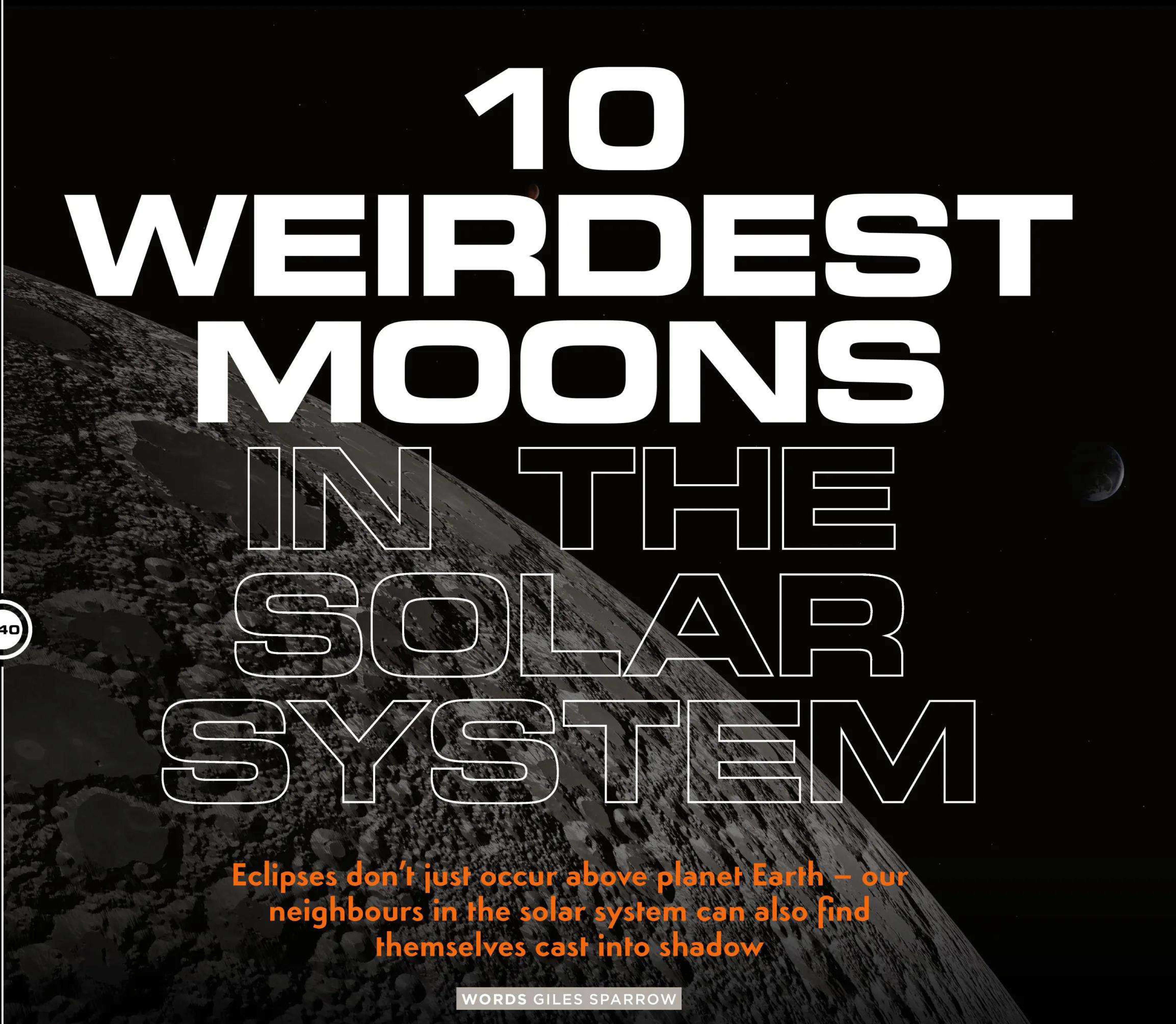
"I feel at this point that anything could be a surprise, or not a surprise, and the honest answer is that we really don't know. I think that's part of why this kind of study adds excitement, at least from my perspective," says Sharkey.

"But we didn't really have a good handle on the question of what Kamoʻoalewa was beforehand and whether other objects could be related in similar ways. The next step is to keep asking that question."

ABOVE: An image of the lunar surface taken on the Apollo 14 mission

RIGHT: Kamoʻoalewa is roughly the size of Italy's Leaning Tower of Pisa





10 WEIRDEST MOONS IN THE SOLAR SYSTEM

Eclipses don't just occur above planet Earth – our neighbours in the solar system can also find themselves cast into shadow

WORDS GILES SPARROW

All but two of our solar system's planets have natural satellites of one sort or another. Earth's own moon, a beautiful but stark, dead world shaped by ancient volcanoes and countless impact craters, is undoubtedly the most familiar, but it's far from being the most interesting. Each of the outer solar system's giant planets is accompanied by a large retinue of satellites, many of which formed at the same time and from the same ice-rich material as the planets around which they orbit. Although far from the Sun and starved of solar heat and light, they nevertheless display as much variety as the planets themselves.

Here we take a trip to visit some of the strangest and most exciting of these astonishing worlds. Some, such as Jupiter's Callisto and Saturn's Mimas, have been frozen solid for billions of years but bear extraordinary scars from space's endless bombardments.

Others, such as Neptune's lonely Nereid, have been affected throughout their history by interactions with their neighbours. Most excitingly, some of these exotic worlds have been heated by powerful tidal forces from their parent planets, triggering phases of violent activity like those that shaped Miranda, Uranus' 'Frankenstein' moon.

In some cases these forces are still at work today, creating fascinating bodies such as Jupiter's tortured Io and Saturn's icy Enceladus, whose placid exterior may even hide the greatest secret in the solar system: extraterrestrial life. Read on to discover some truly bizarre satellites.

1 ENCELADUS

Since NASA's Cassini probe arrived at Saturn in 2004, the ringed planet's small inner satellite, Enceladus, has become one of the most intensely studied and debated worlds in the entire solar system. It owes its relatively new-found fame to the discovery of huge plumes of water ice erupting into space from fissures in its southern hemisphere — a sure sign of liquid water lurking just beneath the moon's thin, icy crust.

The strange activity of Enceladus was suspected before Cassini's arrival thanks to earlier images that showed the moon has an unusually bright surface and craters that look like they are blanketed in snow. Nevertheless, the discovery of the ice plumes — initially made when Cassini flew straight through one — was a spectacular confirmation that Enceladus is an active world.

With a diameter of 504 kilometres (313 miles) and a rock/ice composition, Enceladus should have frozen solid billions of years ago, like many of its neighbours in the Saturnian system. But tidal forces caused by a gravitational tug of war between Saturn and a larger moon, Dione, keep the moon's interior warm and active, making it a prime target in the hunt for life in the solar system.

While much of the water ice falls back to cover the surface, a substantial amount escapes from the weak gravity and enters orbit around Saturn. Here, it spreads out to form the donut-shaped E Ring — the outermost and sparsest of Saturn's major rings.

2 CALLISTO

The outermost of Jupiter's Galilean moons, Callisto is the third-largest moon in the solar system and is only slightly smaller than Mercury. Its main claim to fame is the title of most heavily cratered object in the solar system; its dark surface is covered in craters down to the limit of visibility, the deepest of which have exposed fresh ice from beneath and scattered bright 'ejecta' debris across the surface.

Callisto owes its cratered surface to its location in the Jupiter system — the giant planet's gravity exerts a powerful influence, disrupting the orbits of passing comets and often pulling them to their doom, most spectacularly demonstrated in the 1994 impact of Comet Shoemaker-Levy 9.

Jupiter's larger moons are directly in the firing line and end up soaking up more than their fair share of impacts, but Callisto's inner neighbours — influenced by greater tidal forces — have all experienced geological processes that wiped away most of their ancient craters. Callisto's surface, however, has remained essentially unchanged for more than 4.5 billion years, developing its many overlapping craters across aeons.

"THERE IS A PROBLEM: COMPUTER MODELS SUGGEST DACTYL WOULD BE DESTROYED BY ANOTHER ASTEROID"

3 DACTYL

243 Ida, an asteroid designated as a minor planet, has a moon measuring just 1.6 kilometres (one mile) across on its longest axis. Thanks to the larger asteroid's weak gravity, Dactyl is unlikely to be an object captured into orbit, but the alternative — that Ida and Dactyl formed alongside each other — raises as many questions as it answers.

Ida is a major member of the Koronis family of over 300 asteroids, all of which share similar orbits. The family is thought to have formed 1 or 2 billion years ago during an asteroid collision. Dactyl could be a smaller fragment of debris from the collision that ended up in orbit around Ida, but there is a problem: computer models suggest Dactyl would almost certainly be destroyed by an impact from another asteroid.

So how can it be over a billion years old?

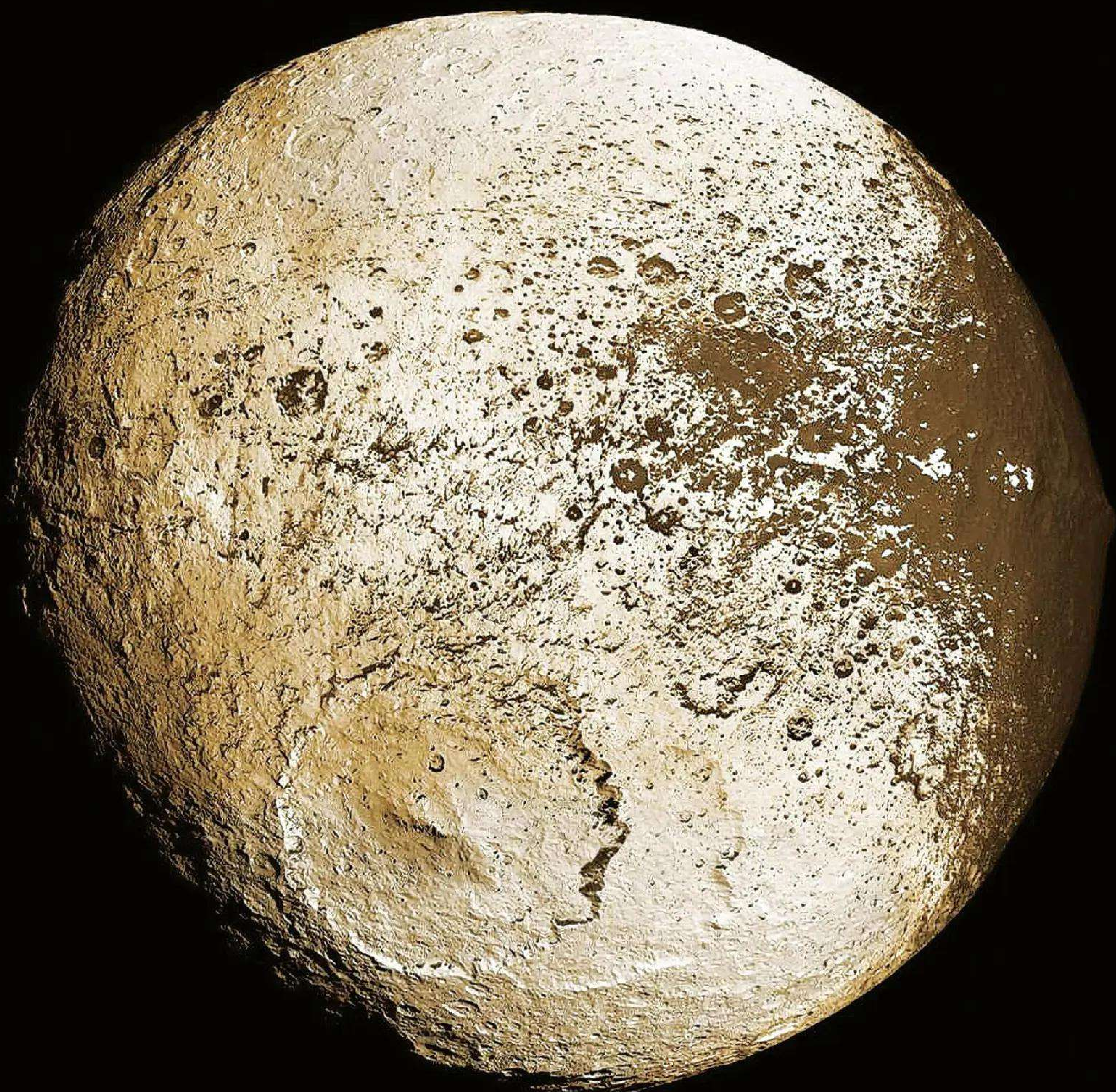
One theory is that the Koronis family is younger than it appears, and Ida's heavy cratering is due to a storm of impacts triggered in the original break-up. Another theory is that Dactyl has suffered a disrupting impact but has pulled itself back together in its orbit, as found by NASA, which might explain its surprisingly spherical shape.

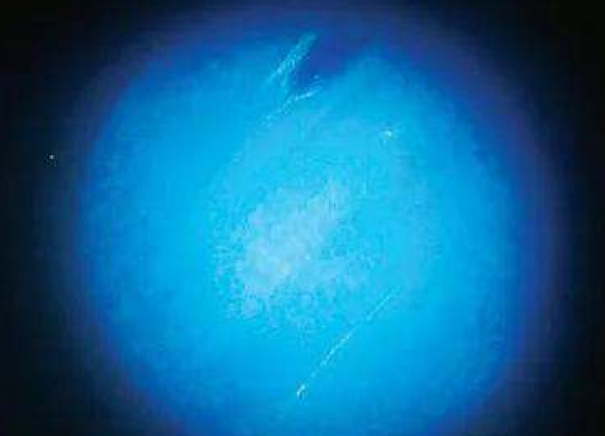
4 IAPETUS

Iapetus has two distinct claims to a place in any list of weird satellites. The first became obvious when it was discovered in 1671 — it is much dimmer when seen on one side of its orbit compared to the other.

Its leading hemisphere — the half that faces 'forwards' as it orbits Saturn — is dark brown, while its trailing hemisphere is light grey. One early theory to explain the colour difference was that the leading side is covered in dust generated by tiny meteorite impacts on small outer moons, which spirals towards Saturn, as found by NASA. However, images from Cassini reveal a more complex story. Most of the dark material seems to come from within Iapetus, left behind as dark 'lag' when dust-laden ice from the moon's surface sublimates (turns from solid to vapour). The process was likely started by dust from the outer moons accumulating on the leading hemisphere, but once it began the tendency of the dark surface to absorb heat has caused a runaway sublimation effect. Iapetus is also ringed by a mountainous equatorial ridge that is 13 kilometres (eight miles) high and 20 kilometres (12 miles) wide, giving the moon its distinctive walnut shape.

The origins of this ridge are puzzling — some theories suggest it is a 'fossil' from a time when Iapetus span much faster and bulged out at the equator, while others think it could be debris from a ring system that once encircled the moon and collapsed onto its surface.





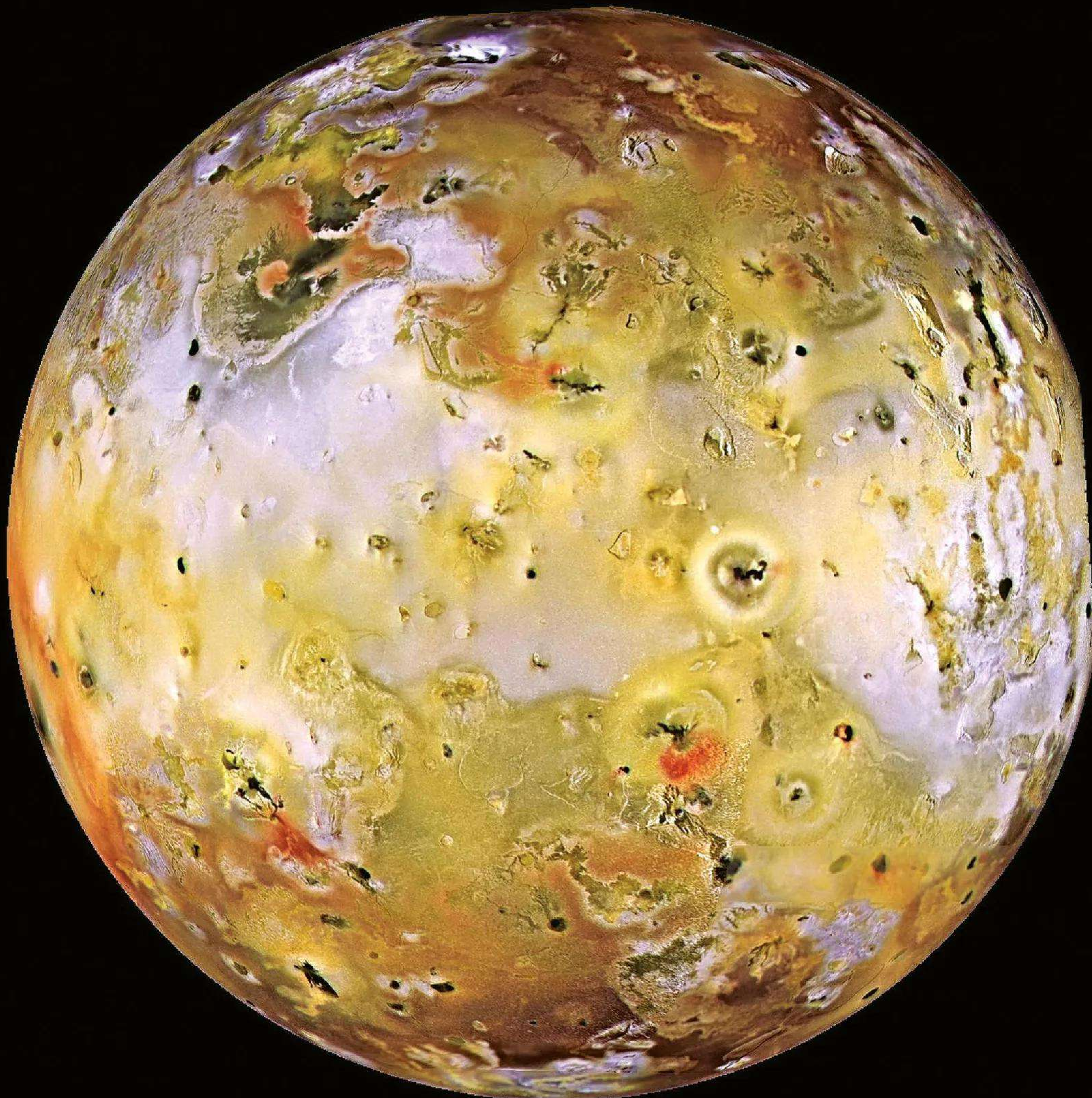
5

NEREID

Nereid was the second moon found to orbit Neptune, and its claim to fame arises from its extreme orbit.

Nereid's distance from Neptune ranges between 1.4 million and 9.7 million kilometres (870,000 and 6 million miles). This orbit is usually typical of captured satellites — asteroids and comets swept up into highly eccentric orbits by the gravity of the giant outer planets — but Nereid's unusually large size suggests a rather more interesting story.

Evidence from Voyager 2's 1989 flyby suggests that Triton was captured into orbit from the nearby Kuiper belt. Triton would have disrupted the orbits of Neptune's original moons, ejecting many of them. But many astronomers believe Nereid could be a survivor, clinging on at the edge of Neptune's gravitational reach.



6

IO

Io is the innermost of the four giant Galilean moons that orbit the solar system's largest planet, Jupiter. But while the outer three are — at least outwardly — placid, frozen worlds of rock and ice, Io's landscape is a virulent mix of yellows, reds and browns, full of bizarre and ever-changing mineral formations created by sulfur that spills onto its surface in many forms.

Io is the most volcanic world in the solar system. Its strange surface was first observed during the Pioneer space probe flybys of the early 1970s, but its volcanic nature was only predicted weeks before the arrival of the Voyager 1 mission in 1979.

The moon is caught in a gravitational tug of war between its outer neighbours and Jupiter itself, and this prevents its orbit from settling into a perfect circle. Small changes in Io's distance from Jupiter — less than 0.5 per cent variation in its orbit — create huge tidal forces that pummel the moon's interior in all directions. Rocks grinding past one another heat up due to friction, keeping the moon's core molten and creating huge subsurface reservoirs of magma.

While the majority of Io's rocks are silicates similar to those on Earth, these have relatively high melting points and so are mostly molten in a hot magma ocean that lies tens of kilometres below the surface — most of Io's surface activity, in contrast, involves sulfur-rich rocks that can remain molten at lower temperatures. Together these two forms of volcanism have long since driven away any icy material, leaving a world that is arid and iceless despite an average surface temperature of -160 degrees Celsius (-256 degrees Fahrenheit) .

7 HYPERION

Hyperion is the strangest-looking satellite in the solar system, its surface resembling a sponge or coral with deep, dark pits rimmed by razor-sharp ridges of brighter rock and ice. But that's not the only thing that's strange about Hyperion: it was the first non-spherical moon to be discovered, and has a distinctly eccentric orbit.

Rather than matching its rotation to its orbital period, it spins in a chaotic pattern, with its axis of rotation wobbling unpredictably. Like all moons in the outer solar system, it's mostly made of water ice, but its surface is unusually dark. When Cassini flew past it measured its density to be 55 per cent that of water. Its interior is mostly empty space.

One popular theory to explain these weird features is that Hyperion is the surviving remnant of a larger satellite that once orbited between Titan and Iapetus and which was largely destroyed by a collision with a large comet. Material that survived in a stable orbit then came together again to create Hyperion as we know it.

8

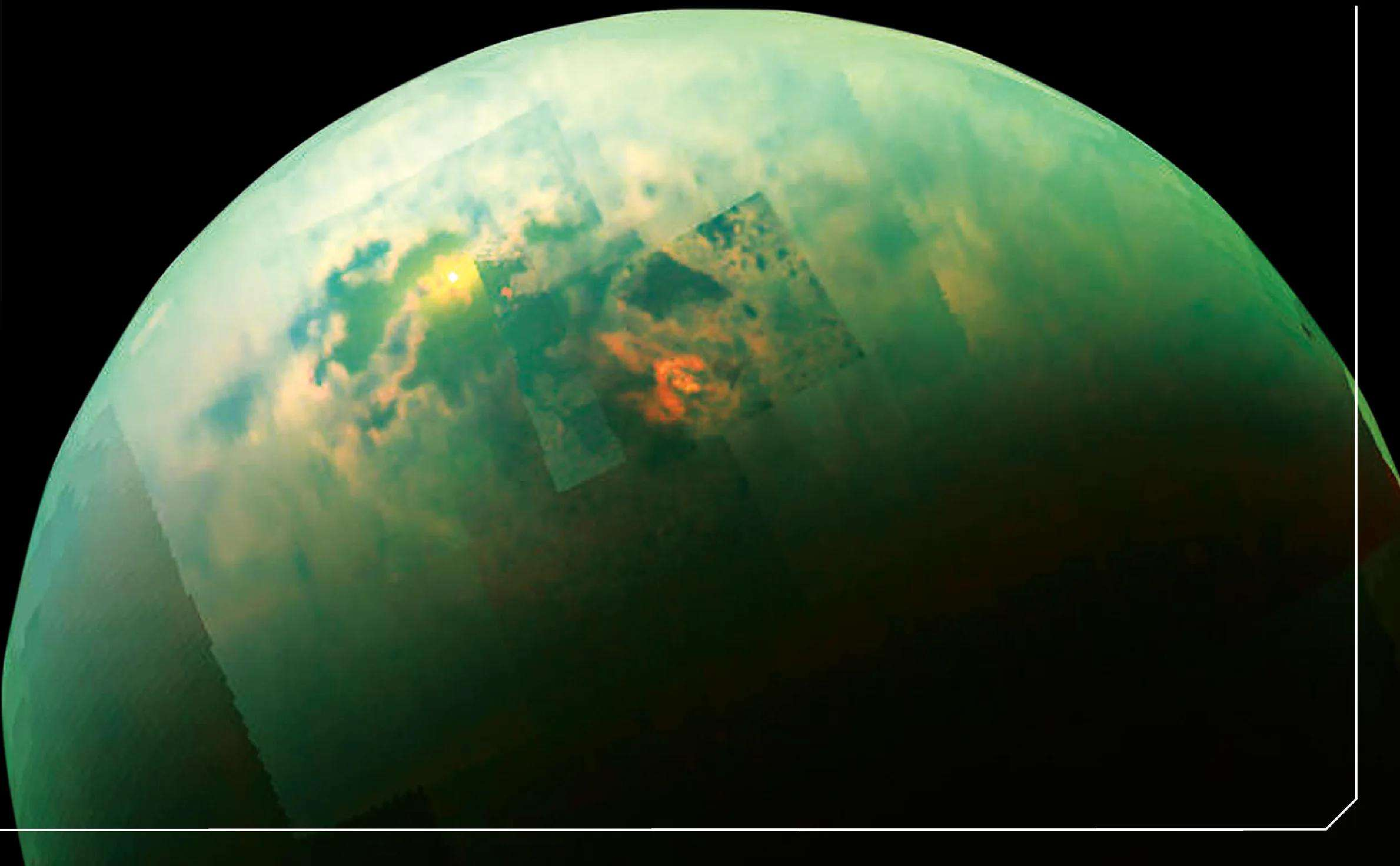
TITAN

Saturn's largest moon is unique in the solar system as the only satellite with a substantial atmosphere of its own — a discovery that frustrated NASA scientists when images from the Voyager probes revealed only a hazy orange ball.

The Cassini orbiter was fitted with infrared and radar instruments that pierced the opaque atmosphere, revealing a softened landscape of rivers and lakes that is unlike any other world in the solar system except for Earth.

Despite being larger than Mercury, Titan can only hold onto its thick atmosphere because of the deep cold. Found some 1.4 billion kilometres (0.9 billion miles) from the Sun, the moon's average surface temperature is a freezing -179 degrees Celsius (-290 degrees Fahrenheit). Titan's atmosphere is dominated by the inert gas nitrogen (also the major component of Earth's air), but it gets its distinctive colour, opaque haze and clouds from a relatively small proportion of methane. Amazingly, conditions on Titan are just right for methane to shift between its gaseous, liquid and solid forms, generating a 'methane cycle' similar to the water cycle that shapes Earth's climate. In cold conditions methane freezes onto the surface as frost and ice. In moderate temperatures, it condenses into liquid droplets and falls as rain that erodes and softens the landscape before accumulating in lakes, while in warmer regions it evaporates into the atmosphere.

Titan experiences changing seasons very similar to those on our planet, though its year is 29.5 Earth years. Temperatures at the winter pole seem to favour rainfall, so the lakes migrate from one pole to the other over each Titanian year. With all this activity, Titan is an intriguing target in the search for extraterrestrial life, though most biologists find it hard to envision organisms that could exist in such harsh and chemically limited conditions, and most agree that Titan's watery neighbour Enceladus offers more promising prospects for life.



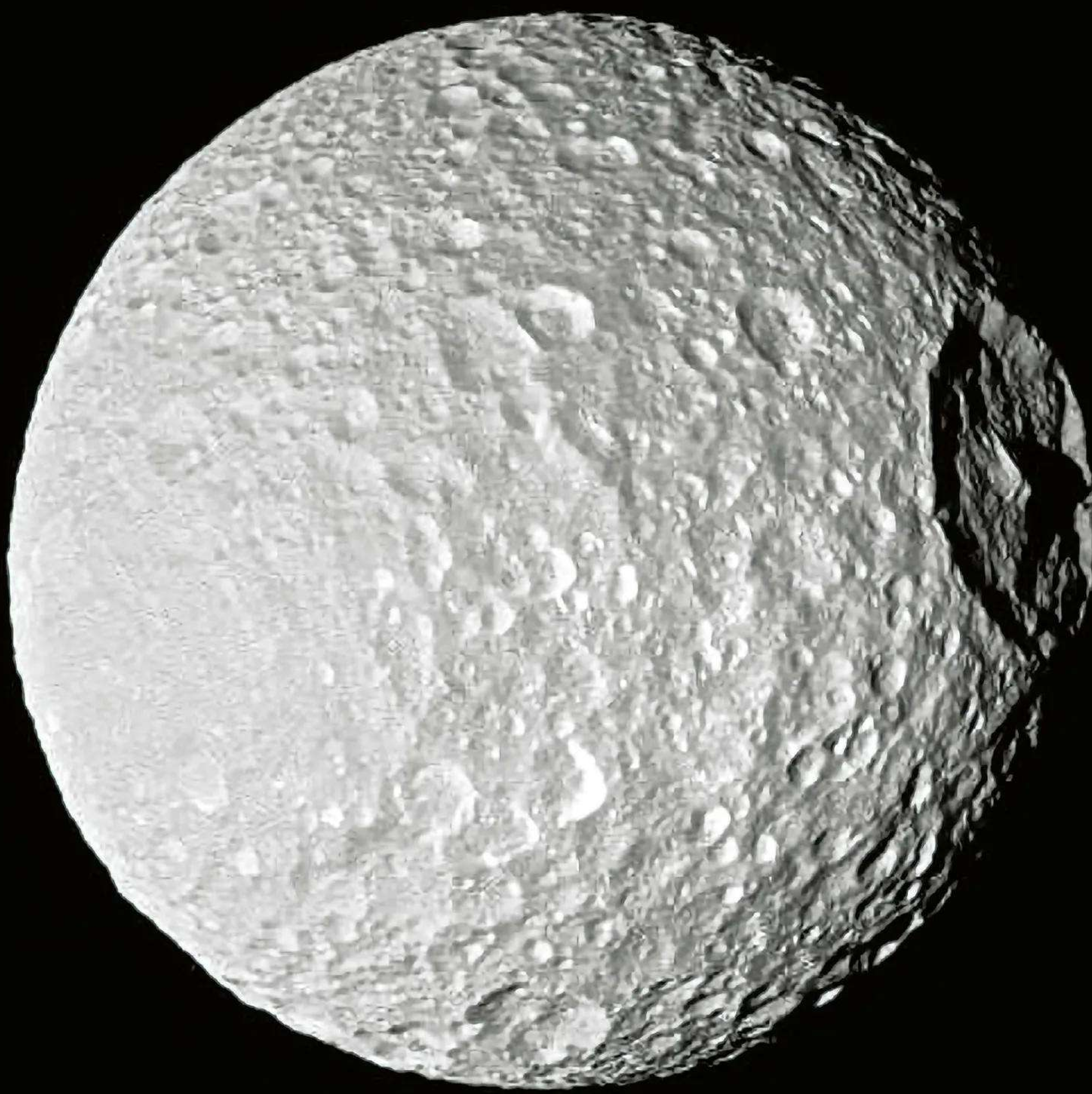
9

MIRANDA

Miranda is one of the strangest worlds in the solar system. Voyager images revealed an extraordinary patchwork of terrains, seemingly put together at random. Some parts are heavily cratered and some relatively uncratered — indicating their youth, as they have been less exposed to bombardment. One prominent feature is a pattern of concentric ovals resembling a race track, while elsewhere parallel V-shapes form a chevron-like scar.

An early theory to explain Miranda's jumbled appearance is that it is a 'Frankenstein' world — a collection of fragments from a predecessor moon that coalesced in orbit around Uranus. Astronomers wondered whether Miranda's predecessor might have been shattered by an interplanetary impact and whether this cataclysmic event might somehow be linked to Uranus' own extreme tilt. Further studies, however, have shown that such a theory comes up short when trying to explain Miranda's mix of surface features, and the right kind of impact is unlikely. Instead it seems plausible that tidal forces are to blame.

Today Miranda follows an almost-circular orbit, but in the past its orbit was in a 'resonant' relationship with the larger moon Umbriel. This brought the two moons into frequent alignments that pulled Miranda's orbit into an elongated ellipse that experienced extreme tidal forces. Pushed, pulled and heated from within, its surface fragmented and rearranged itself before the moons moved again and Miranda's activity subsided.



10

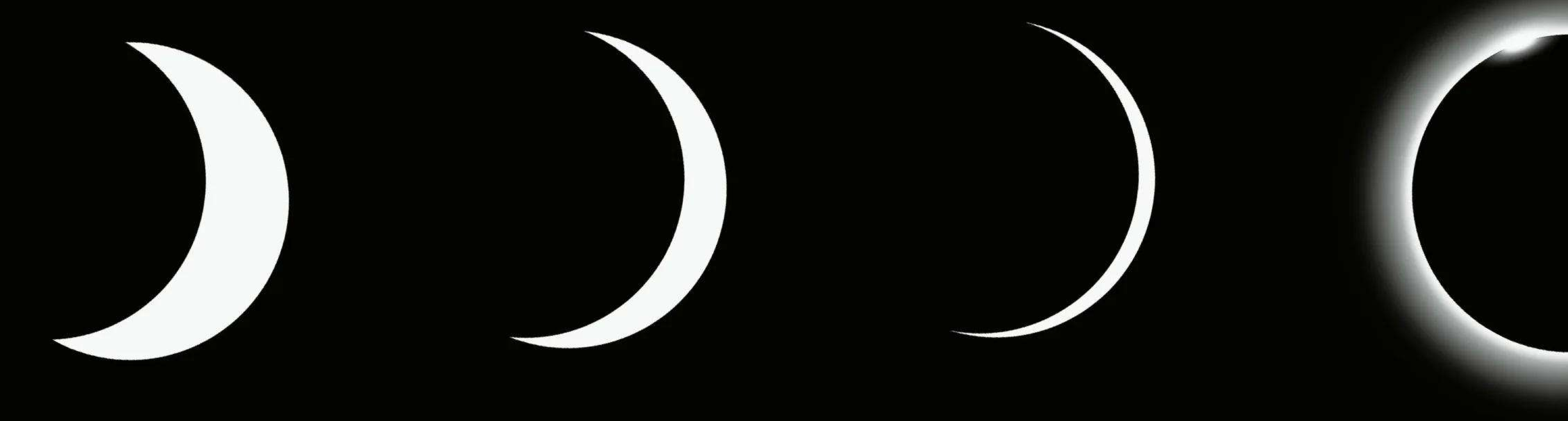
MIMAS

When NASA's Voyager space probes sent back the first detailed images of Mimas in the 1980s, scientists and the public were shocked by its resemblance to the Death Star from Star Wars. A huge crater named after William Herschel, who discovered the moon in 1789, dominates one hemisphere and is almost the exact size and shape of the planet-killing laser dish dreamt up by George Lucas in the 1970s. But Mimas has more to offer than pop-cultural references.

Mimas is the innermost of Saturn's substantial moons — orbiting closer than Enceladus but further out than Pan and Atlas — and with a diameter of just 396 kilometres (246 miles), it's the smallest object in the solar system known to have pulled itself into a spherical shape from its own gravity. Some larger objects haven't managed this, and most astronomers agree that it's only possible for Mimas because of the moon's low density, which is just 15 per cent greater than water.

TRACING THE SKIES

Photographed over Alberta, Canada, on 27 October 2004, this image shows the luminescent motion trail of a total lunar eclipse.



BEHOLD: BAILY'S BEADS

We explore the science behind a sparkling light show that's all down to the Moon's many craters

WORDS LEE CAVENDISH

As the world looks collectively toward the sky in eager anticipation of a solar eclipse, one of the sensations that observers can feast their eyes upon are Baily's beads. Much like a radiant necklace within the cosmic jewellery box, these beads would not be out of place even in the grandeur of Andromeda herself. Within this rare, breathtaking yet fleeting moment, the Sun and the Moon combine in a dance of shadow and light to create a row of radiant beads.

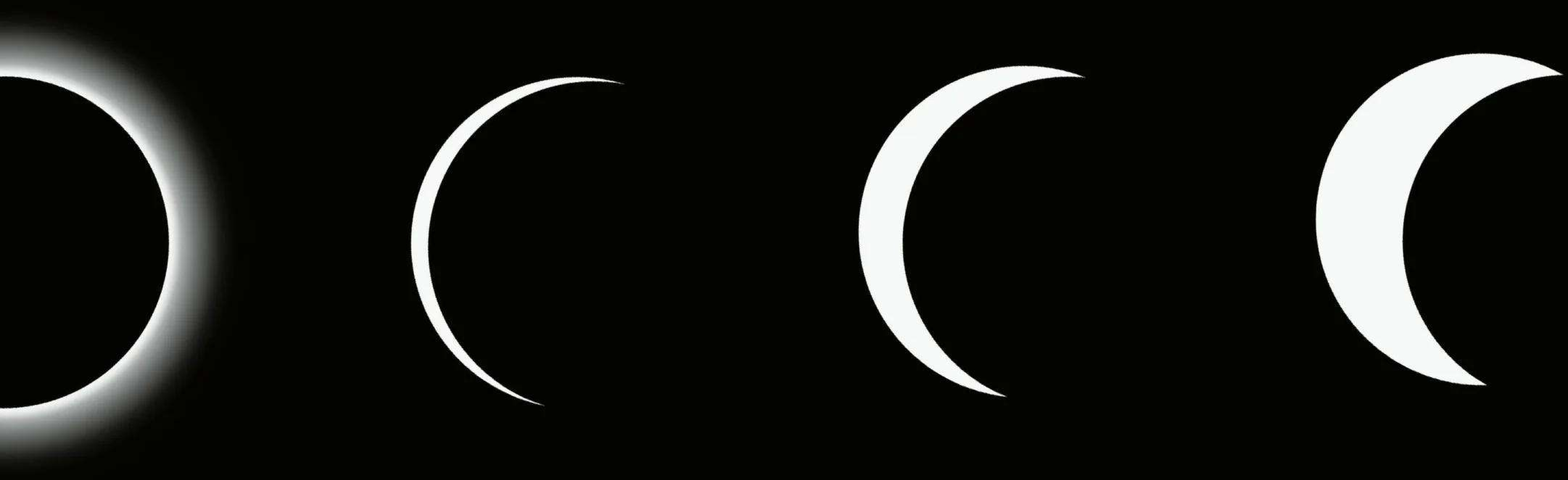
The opportunities to catch a glance of Baily's beads are few and far between, with solar eclipses occurring between two and five times a year anywhere around the globe. These dazzling rays of light are created during annular solar eclipses and total solar eclipses. A total solar eclipse is the more popular of the two, as the apparent sizes of the Moon and the Sun almost perfectly align, equating to complete coverage essentially. This is a truly fantastic spectacle to be a part of, as the land around you darkens for seconds or even minutes, making one feel as if they've just entered the upside-down.

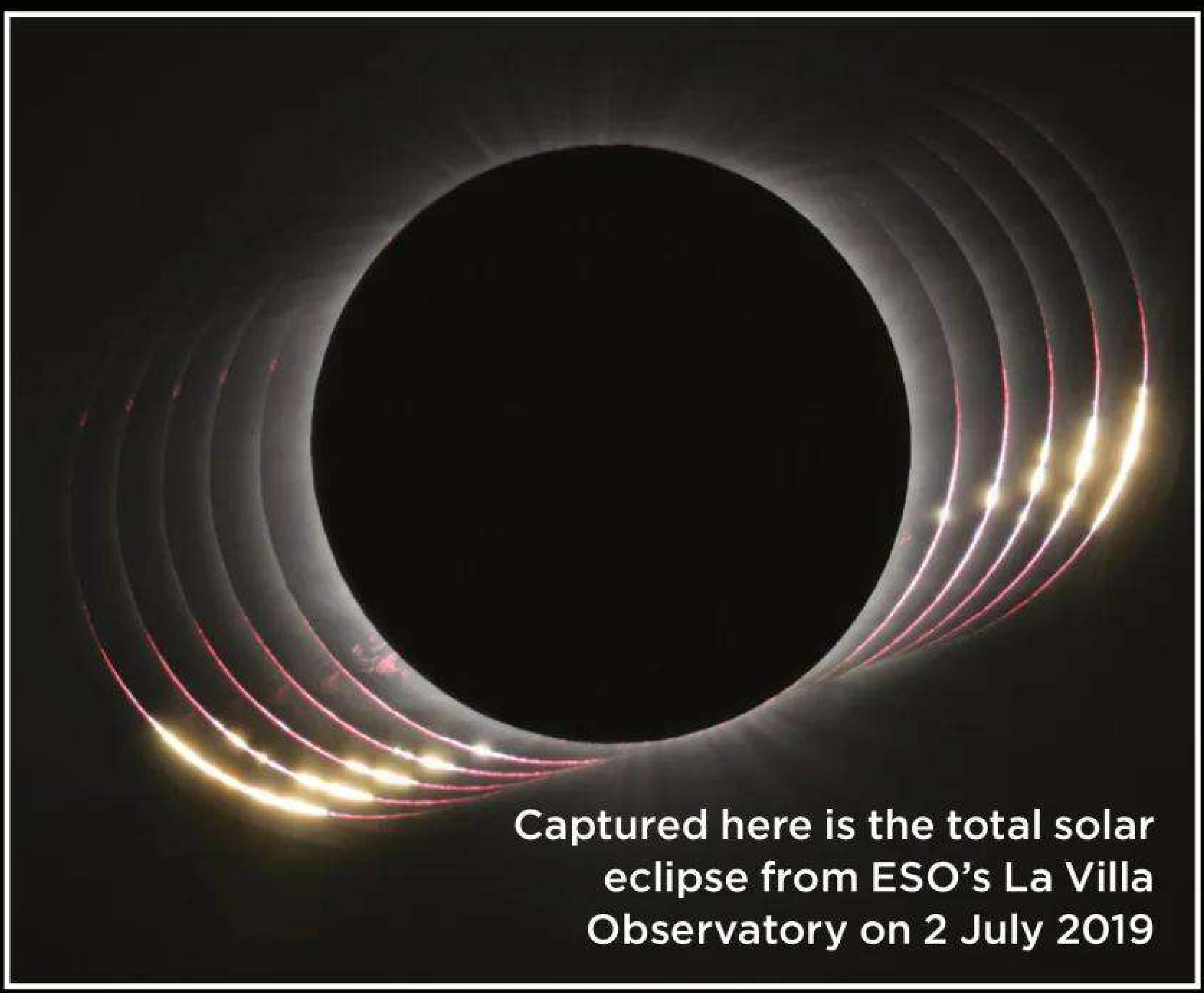
During an annular eclipse, the Moon is slightly further away from Earth (in apparent terms), therefore allowing more of the Sun's photosphere to show. This may not make it dark, but it is still an spectacle to watch.

A total solar eclipse can be split into four different stages: first contact, second contact, third contact and (you guessed it) fourth contact. When the Moon's silhouette begins to obscure the Sun's disc, causing a crescent of darkness to appear on the Sun's surface, this is referred to as the first contact. Second contact marks the beginning of totality, where the Sun's photosphere is completely covered, leaving the solar corona as the only faintly visible light. After a few seconds of totality, third contact marks the end of the total eclipse and sunlight returns to Earth. Finally, after a collective sigh of disappointment marking the end of the eclipse, the fourth contact stage occurs as the Moon moves away from the Sun until it no longer obscures it.

Eclipses have been a focus of study ever since the telescope was invented in 1604. In regards to Baily's beads, the earliest observation of them can be traced back to Sir Edmund Halley studying a total eclipse on 22 April 1715. However, they are not called 'Halley's beads'. The reason for that is because it was one of the Royal Astronomical Society's founding fathers, a man named Francis Baily, who brought this feature to public attention. This 19th-century businessman turned astronomer took his 6.6-centimetre (2.6-inch) refractor telescope to Scotland on 15 May 1836 to observe an annular solar eclipse.

As Baily spent the majority of his scientific studies on eclipses, he took this opportunity to carefully study the eclipse throughout its entirety. In the seconds during the second contact stage, Baily





Captured here is the total solar eclipse from ESO's La Villa Observatory on 2 July 2019

noted "a row of lucid points, like a string of beads, irregular in size and distance from each other".

These spots of light sitting on the rim of the Moon's silhouette are caused by the Moon's unequal topography. Much like the Earth, the Moon is covered in mountains, valleys and craters that make for anything but a smooth surface. These 'beads' are sunlight shining through the uneven lunar surface in the seconds leading up to totality and the seconds after. During the same period, observers can also marvel at the Diamond Ring effect, which is the name given to the final, much grander flash of light concentrated on one side of the Moon. Another one to add to the jewellery box!

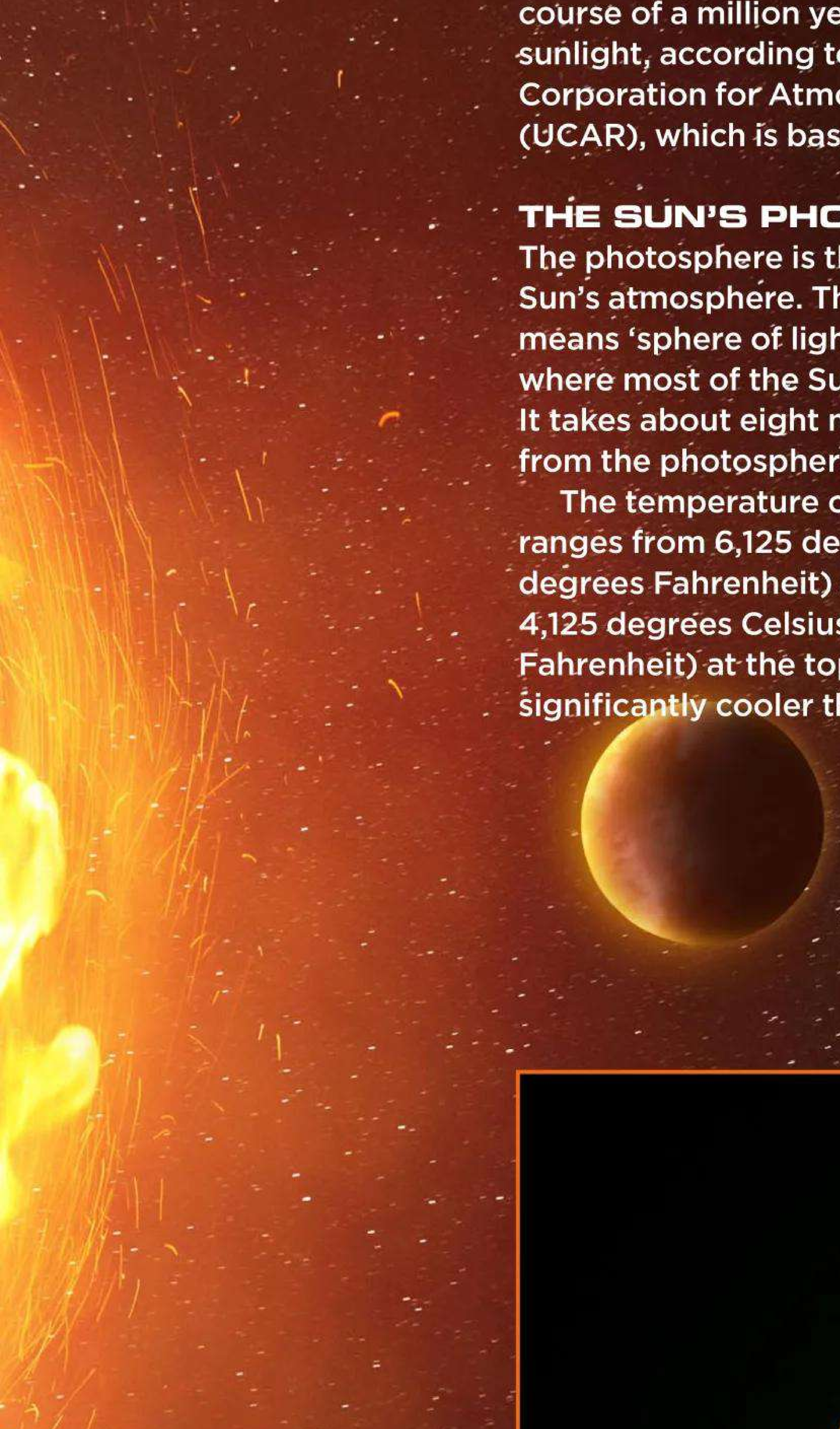
If anyone is fortunate enough to travel the world and observe solar eclipses and Baily's beads, two things are needed. To observe this spectacle, the first thing that is needed is a telescope or a powerful pair of binoculars — a 30x magnification is recommended. Second is a solar filter. The latter is vitally important as sunlight, even if it is largely covered by the Moon, can still cause damage to our eyes, and before you ask, no, sunglasses are not enough.

To observe an eclipse and catch this captivating spectacle, don't forget your solar filter

SECRETS OF THE SUN: PHOTOSPHERE, CHROMOSPHERE AND CORONA

Each layer of the Sun's atmosphere exhibits its own distinct traits

WORDS TIM SHARP



The Sun's atmosphere is comprised of several different layers, but the main ones are the photosphere, the chromosphere and the corona. It's inside these outer layers that the Sun's energy, which has bubbled up from the Sun's interior layers over the course of a million years, is detected as sunlight, according to the University Corporation for Atmospheric Research (UCAR), which is based in Colorado.

THE SUN'S PHOTOSPHERE

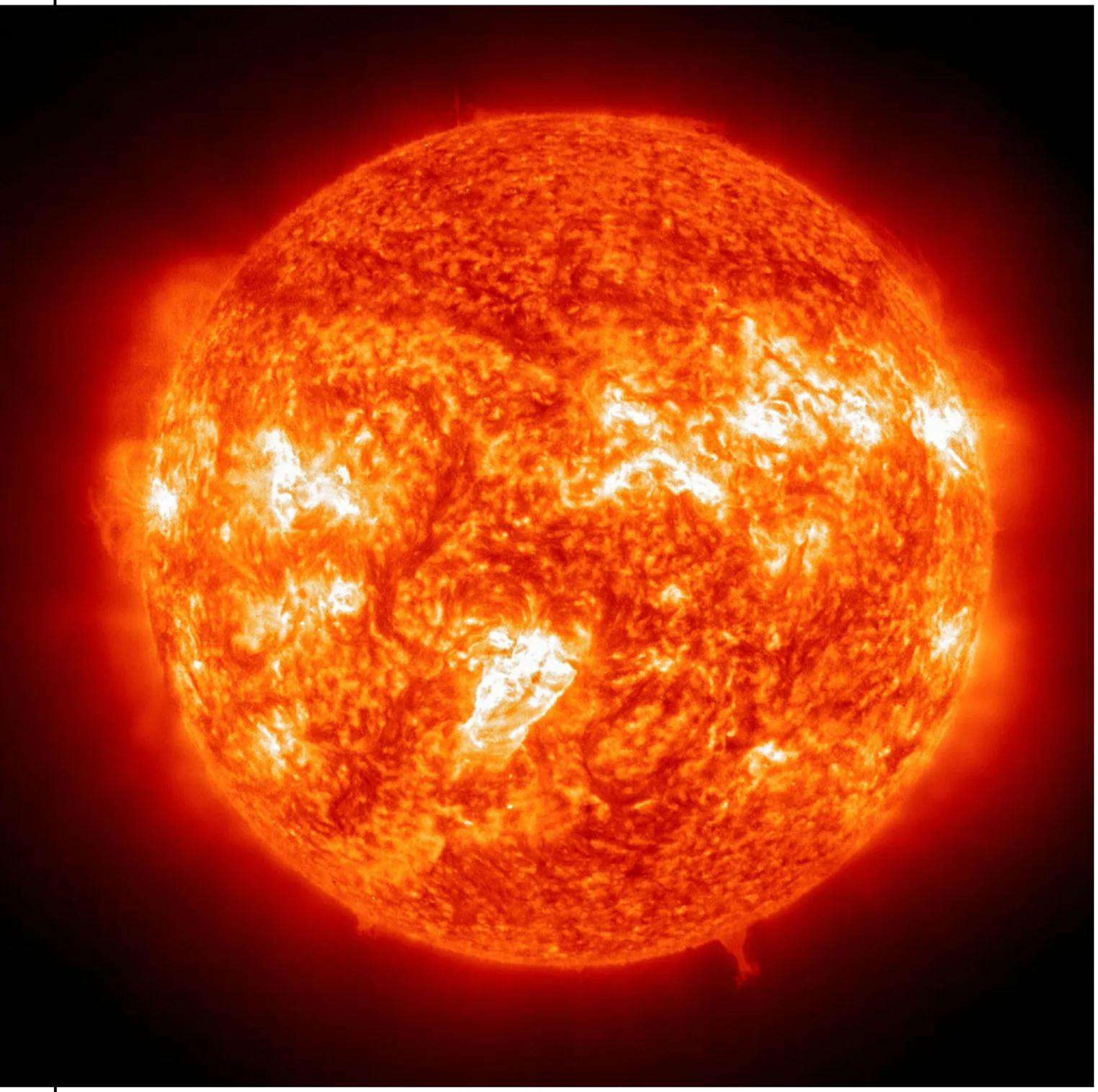
The photosphere is the lowest layer of the Sun's atmosphere. The term photosphere means 'sphere of light' and is the layer where most of the Sun's energy is emitted. It takes about eight minutes for sunlight from the photosphere to reach Earth.

The temperature of the photosphere ranges from 6,125 degrees Celsius (11,000 degrees Fahrenheit) at the bottom to 4,125 degrees Celsius (7,460 degrees Fahrenheit) at the top. The photosphere is significantly cooler than the Sun's core, which can reach about 15 million degrees Celsius (27 million degrees Fahrenheit) according to NASA. The Sun's photosphere is about 500 kilometres (300 miles) thick, which is relatively thin when compared with the 700,000-kilometre (435,000-mile) radius of the Sun.

The photosphere is marked by bright, bubbling granules of plasma and darker, cooler sunspots, which emerge when the Sun's magnetic field breaks through the surface. When this occurs sunspots appear to move across the Sun's disc. Observing this motion led astronomers to realise that the Sun rotates on its axis. Since the Sun is a ball of gas with no solid form, different regions rotate at different rates. The Sun's equatorial regions complete a rotation roughly every 24 days, while the polar regions take more than 30 days to make a complete rotation.

The photosphere is also the source of solar flares, tongues of fire that extend for hundreds of thousands of miles and produce bursts of X-rays, ultraviolet radiation, electromagnetic radiation and radio waves.

The Sun's photosphere is the innermost layer that we can observe directly



solar scientist at Stanford University in Stanford, California, and lead author of a study that tracked waves from sunspots said in a statement.

"This research gives us a new viewpoint to look at waves that can contribute to the energy of the atmosphere."

THE SUN'S CORONA

The third layer of the Sun's atmosphere is the corona. Like the chromosphere, the Sun's corona can only be seen during a total solar eclipse (or with NASA's Solar Dynamics Observatory). It appears as white streamers or plumes of ionized gas that flow outward into space. Temperatures in the Sun's corona can get as high as 2 million degrees Celsius (3.5 million degrees Fahrenheit). As the gases cool, they become the solar wind.

Why the corona is up to 300-times hotter than the photosphere, despite being farther from the solar core, has remained a long-term mystery.

"That's a bit of a puzzle," Jeff Brosius, a space scientist at Catholic University in Washington, D.C., and NASA's Goddard Space Flight Center in Greenbelt, Maryland, said in a statement. "Things usually get cooler farther away from a hot source. When you're roasting a marshmallow you move it closer to the fire to cook it, not farther away."

Research suggests that tiny explosions known as nanoflares may help to massively increase the temperature by providing sporadic bursts that can reach up to a truly

THE SUN'S CHROMOSPHERE

The layer above the photosphere is called the chromosphere. The chromosphere emits a reddish glow as super-heated hydrogen burns off, but the red rim can only be seen during a total solar eclipse. At other times, light from the chromosphere is usually too weak to be seen against the brighter photosphere.

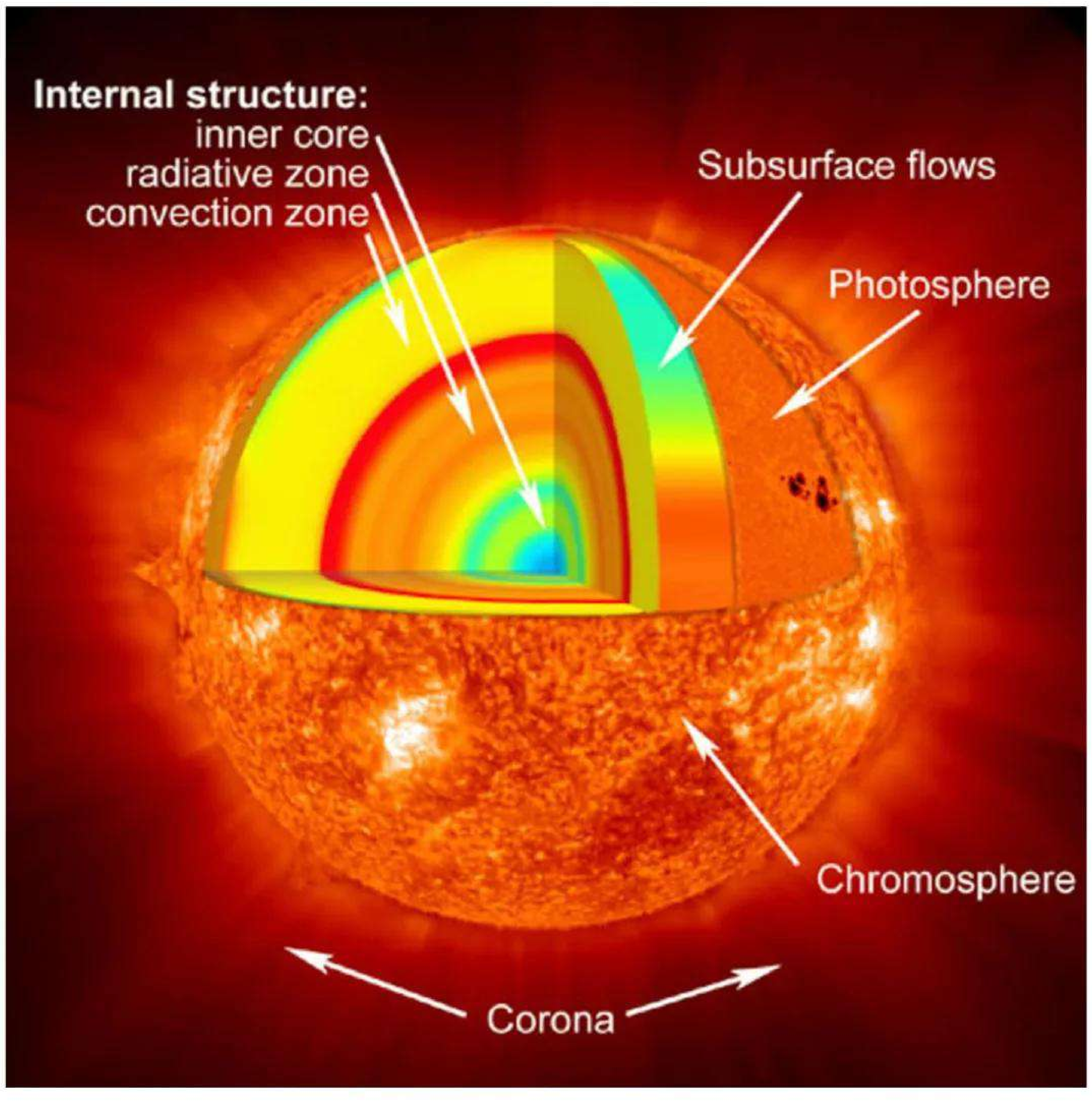
The chromosphere may play a role in conducting heat from the interior of the Sun to its outermost layer, the corona.

"We see certain kinds of solar seismic waves channelling upwards into the lower atmosphere, called the chromosphere, and from there, into the corona," Junwei Zhao, a

"WHY THE CORONA IS UP TO 300-TIMES HOTTER THAN THE PHOTOSPHERE HAS REMAINED A LONG-TERM MYSTERY"

ABOVE: The chromosphere emits a reddish glow as super-heated hydrogen burns off

RIGHT: This diagram reveals the anatomy of our colossal star



roasting 10 million degrees Celsius (18 million degrees Fahrenheit).

"The explosions are called nanoflares because they have one-billionth the energy of a regular flare," Jim Klimchuk, a solar scientist at NASA's Goddard Space Flight Center, said in a statement. "Despite being tiny by solar standards, each packs the wallop of a 10-megaton hydrogen bomb. Millions of them are going off every second across the Sun, and collectively they heat the corona."

Super-tornados may also play a role in heating the Sun's outer layer. These solar twisters are a combination of hot-flowing gas and tangled magnetic field lines that are driven by nuclear reactions in the solar core.

"Based on the detected events, we estimate that at least 11,000 swirls are present on the Sun at all times," Sven Wedemeyer-Böhm, a solar scientist at the University of Oslo in Norway and lead author of the team that identified tornados on the Sun, told **Space.com**.

Recent research suggests that solar "campfires" — miniature solar flares discovered by the European-U.S. Solar Orbiter mission could be behind the mysterious heating of the Sun's corona.

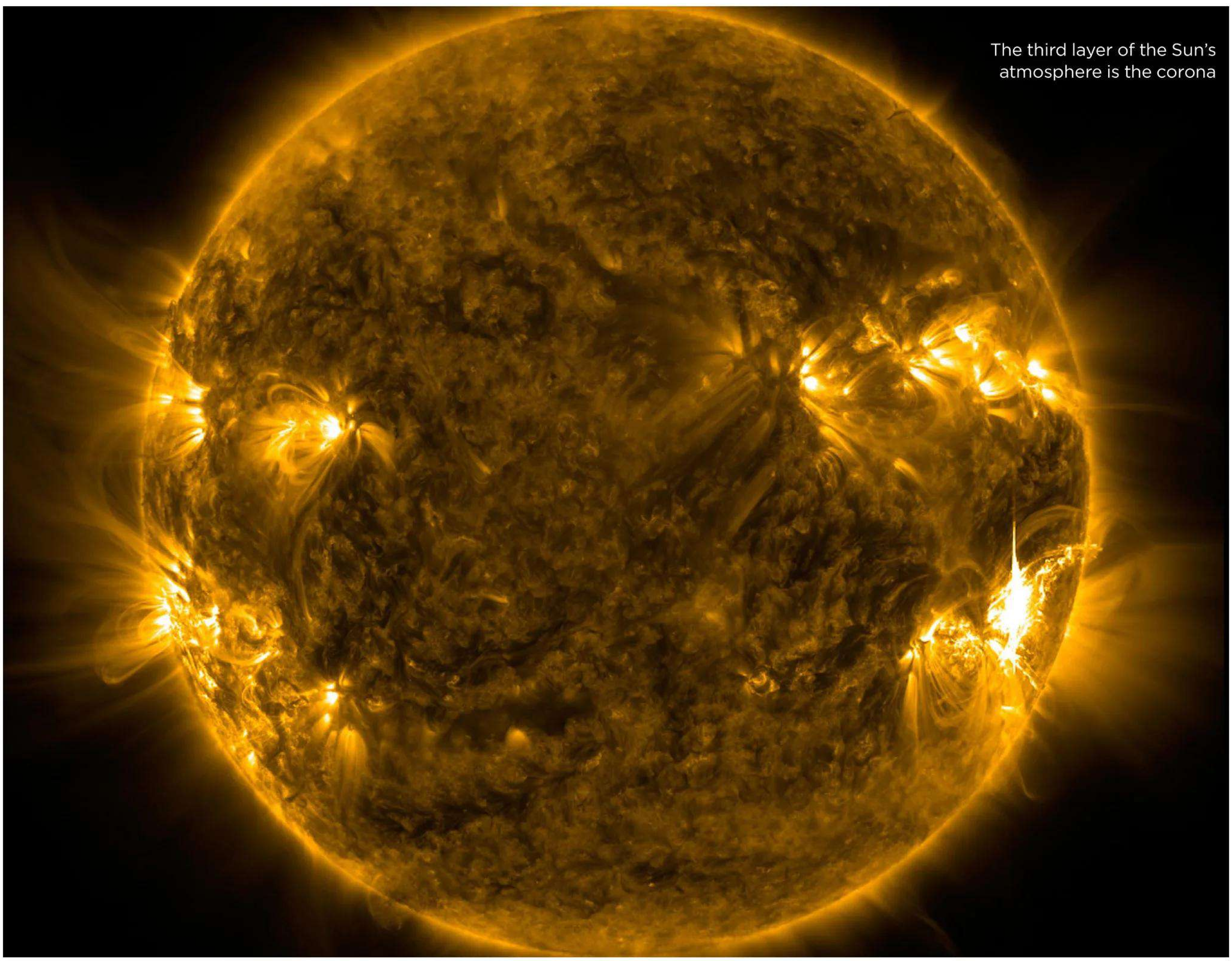
THE SUN'S ATMOSPHERE: LATEST RESEARCH

In 2016, NASA's Solar Dynamics Observatory and the Solar Heliospheric Observatory observed a large "missing link" explosion on the Sun. The event showed characteristics of three different types of solar eruptions that usually happen separately but occurred together this time, **Space.com** previously reported.

Scientists are studying the unique event to uncover new information about what causes these powerful solar eruptions and how we might be able to better predict them in the future.

On 3 July 2021, the Sun surprised everyone with an enormous solar flare so large it caused a brief radio blackout on Earth according to officials. At the end of 2023 it then unleashed the strongest solar flare in six years.


The ISS basks in the searing rays of the Sun


The third layer of the Sun's atmosphere is the corona

A hibiscus closes its petals during an eclipse

HOW SOLAR ECLIPSES IMPACT MOTHER NATURE

From flowers spontaneously shutting their petals to thousands of salmon washing ashore, eclipses can have a downright strange effect on plants and animals

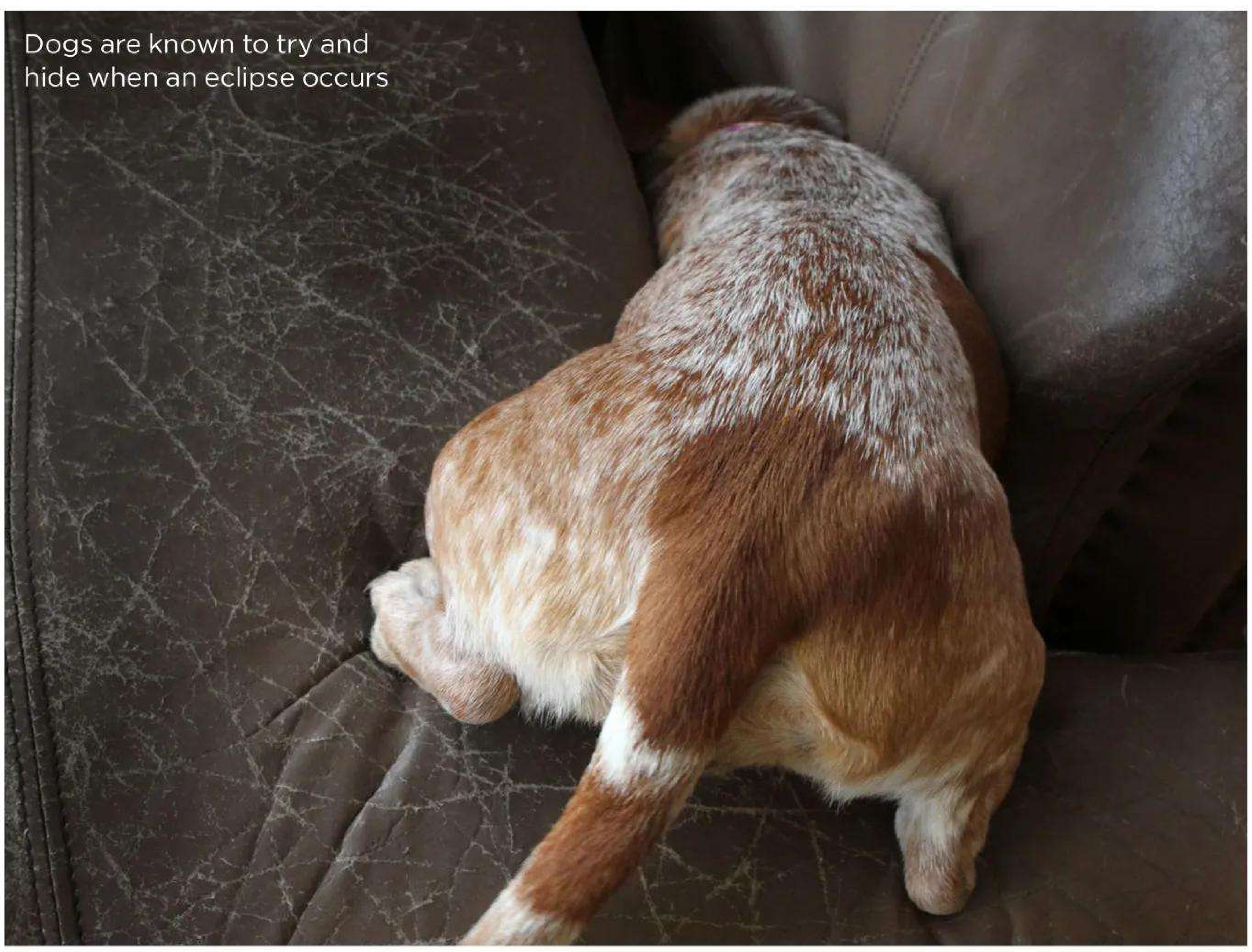
WORDS TIA GHOSE

It's no secret that animals are highly sensitive creatures in tune with their surroundings, so it's not surprising that an eclipse might influence their behaviour. Even so, these events can make animals (and plants) move in mysterious ways, and thanks to studies conducted during the solar eclipse of August 2017, we have plenty of evidence to support this.

Several experimental projects were aimed at recording the responses of animals to the eclipse, including the iNaturalist app, which encouraged people to record observations during and after totality, says Rebecca Johnson, citizen science research director at the California Academy of Sciences in San Francisco. Johnson, along with colleagues, helped spearhead the effort to gather these observations and sift through them — once the Sun had returned.

It turned out that the solar eclipse didn't just make humans go crazy and indulge in

Naturally playful, horses have been reported bucking and jumping prior to an eclipse



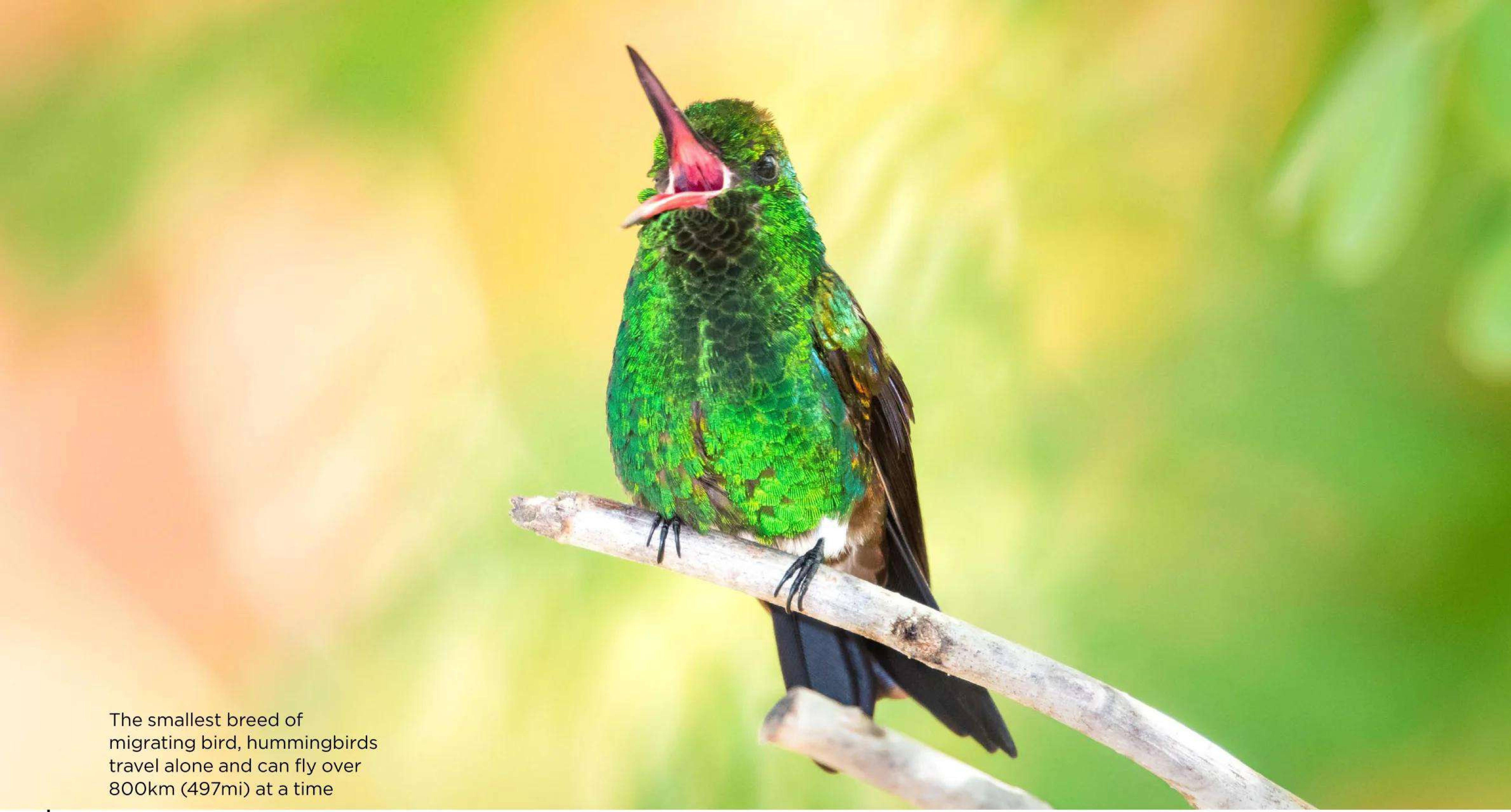
Dogs are known to try and hide when an eclipse occurs

odd behaviour; it also had a wide range of effects on flora and fauna throughout the natural world. From jittery horses to hungry fish, here are some of the most interesting impacts of the eclipse on nature.

PETS

Many animals have strong day-night behaviour patterns that are tied to cycles of light and dark, as well as temperature. In the past, researchers have observed bizarre behaviour in insects, chimpanzees and baboons in response to eclipses, Live Science previously reported.

But the 2017 eclipse was different in that it occurred in such a widely populated area. This enabled many different experiments to be conducted to gather citizen-science observations, Johnson says. More than 500 people using the iNaturalist app made about 2,100 observations involving over 350 different species. Of course, the animals that were most closely observed were the cats and dogs that came along with people on their eclipse-viewing trips.



The smallest breed of migrating bird, hummingbirds travel alone and can fly over 800km (497mi) at a time

Many of the reports coming into Johnson were of dogs that seemed to be reacting to the eclipse during totality.

While reports came in about cats seeming to be upset as well, it's a little tougher to decipher their behaviour, Johnson says. For instance, Sean Carroll, a theoretical physicist at the California Institute of Technology, noted on Twitter that the celestial anomaly was "spooking" one of his cats, while the other remained its "chill" self. "Personality overrides astronomy," Carroll concluded.

In general, figuring out why a domestic cat does anything is a little tougher, Johnson says. "I would be really loath to try to figure out what my cat was actually doing. But dogs, their behaviours are a little more transparent."

FARM ANIMALS

Domestic chickens also reacted to the sky-darkening effect, but they seemed more strongly impacted by the temperature, says Tim Reinbott, director of field operations at the College of Agriculture at the University of Missouri.

The day of the eclipse was hot, but as the Sun was blocked the temperature dropped considerably. The most notable effect on the chickens was that they came out from under their coop, where they usually hide during the heat of the day. Then, at totality, they started grooming themselves, as they usually do in the evening. When the Sun returned, they went back to hiding under their coops, Reinbott says.

Horses also seemed to be spooked. "After the eclipse was over, the foals just went crazy," reveals Reinbott. "They started whinnying, they started running, jumping. I guess they felt like it was evening."

INSECTS, BIRDS AND OTHER CREATURES

Reinbott also noticed insects changing their tune. "Right before the eclipse, the cicadas, the insects got really loud, and then when it got to the eclipse everything went silent," Reinbott says. "It was kind of eerie."

Citizen observers also noted several reports of birds flying in huge formations, while others (especially hummingbirds) changed their song patterns, either by becoming very noisy or going quiet.

The impact of the eclipse wasn't just restricted to the land and skies; Reinbott heard reports from friends who went fishing that the eclipse affected their catches."Right before totality, boom, the big fish started hitting!"

That's likely because big fish tend to feed early in the morning and early in the evening, and the darkening skies confused them, Reinbott explains.

"WHILE REPORTS CAME IN ABOUT CATS SEEMING TO BE UPSET AS WELL, IT'S A LITTLE TOUGHER TO DECIPHER THEIR BEHAVIOUR"

Sensitive to eclipses, felines are also known to vanish before an earthquake occurs

OTHER EFFECTS

Not every event in nature was due to strange animal behaviour per se. For instance, in a truly odd occurrence, the exceptionally strong tides caused by the eclipse ripped a net penning salmon on a fish farm near Bellingham Bay in Washington. Up to 305,000 Atlantic salmon washed ashore in those waters, all thanks to the eclipse, *The Seattle Times* reported.

Officials in the area urged people to catch as many of these loosed salmon as possible, as they posed an environmental hazard to the area and could threaten wild Pacific salmon that are native to the habitat.

When it came to plants, which obviously rely on light for photosynthesis, there were also some interesting results. For instance, many citizen observers snapped photos of flowers like morning glories or hibiscus (which typically close their petals at night in order to keep their pollen dry) doing the same as the totality approached, then opening again once the Sun returned, Johnson says.

The name cicada is derived from the Latin word for 'tree cricket'

Female Atlantic salmon can lay between 2,500 and 7,000 eggs

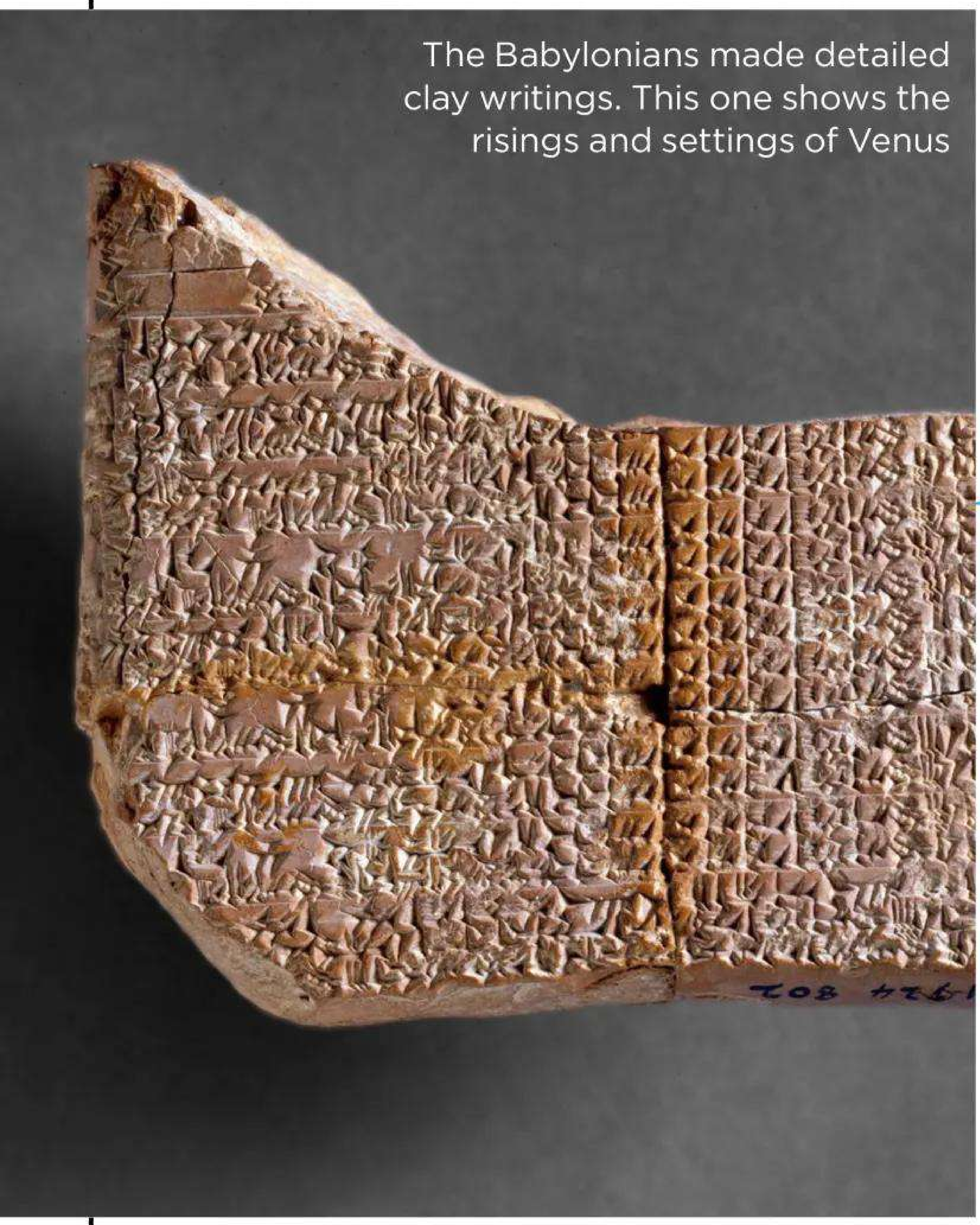
SECTION 2

SHADOW OF HISTORY


© Getty

Babylonians watched eclipses in fear of what fatal event could occur

MESOPOTAMIAN MOON-WATCHERS



The Babylonians made detailed clay writings. This one shows the risings and settings of Venus

How were celestial alignments predicted and interpreted by this ancient civilisation?

WORDS AILSA HARVEY

The astronomers of ancient Babylonia (1894–1595 BCE) are renowned for their detailed surveys of the skies and accurate predictions of astronomical events. The Babylonians spent much time gazing up at the heavens and analysing such events as they illuminated the boundless canvas above daily life. By tracking the movements of the Sun and Moon, astronomers were able to produce the first known lunar and solar calendars and plan for optimal crop-growing seasons. By carefully plotting the movements of celestial objects across the sky, the Babylonians also documented early predictions of eclipses.

Despite holding high importance, the occurrence of a lunar eclipse was not a celebratory event for everybody. In fact they were considered to be bad omens for Babylonian kings. After all, without fully understanding the presentations of the sky before them, an event whereby the Sun temporarily disappears from view could be a frightening sight.

Before Babylonians learned to forecast them, there was nothing a king could do to remain safe. But once astronomers became successful in foretelling these events action was taken to save their royalty — albeit at the expense of another man. Before an eclipse, a new king was appointed in substitution. Prior to the looming eclipse, the real king would go into hiding, while the substitute king was throned and robed to deceive onlooking gods. This didn't last long, however. Everyone would gather to watch the eclipse in fear of what it would bring to the community. Then, following the

eclipse, the substitute was to be killed as a sacrifice, thereby taking fate into their own hands to keep the real king from harm.

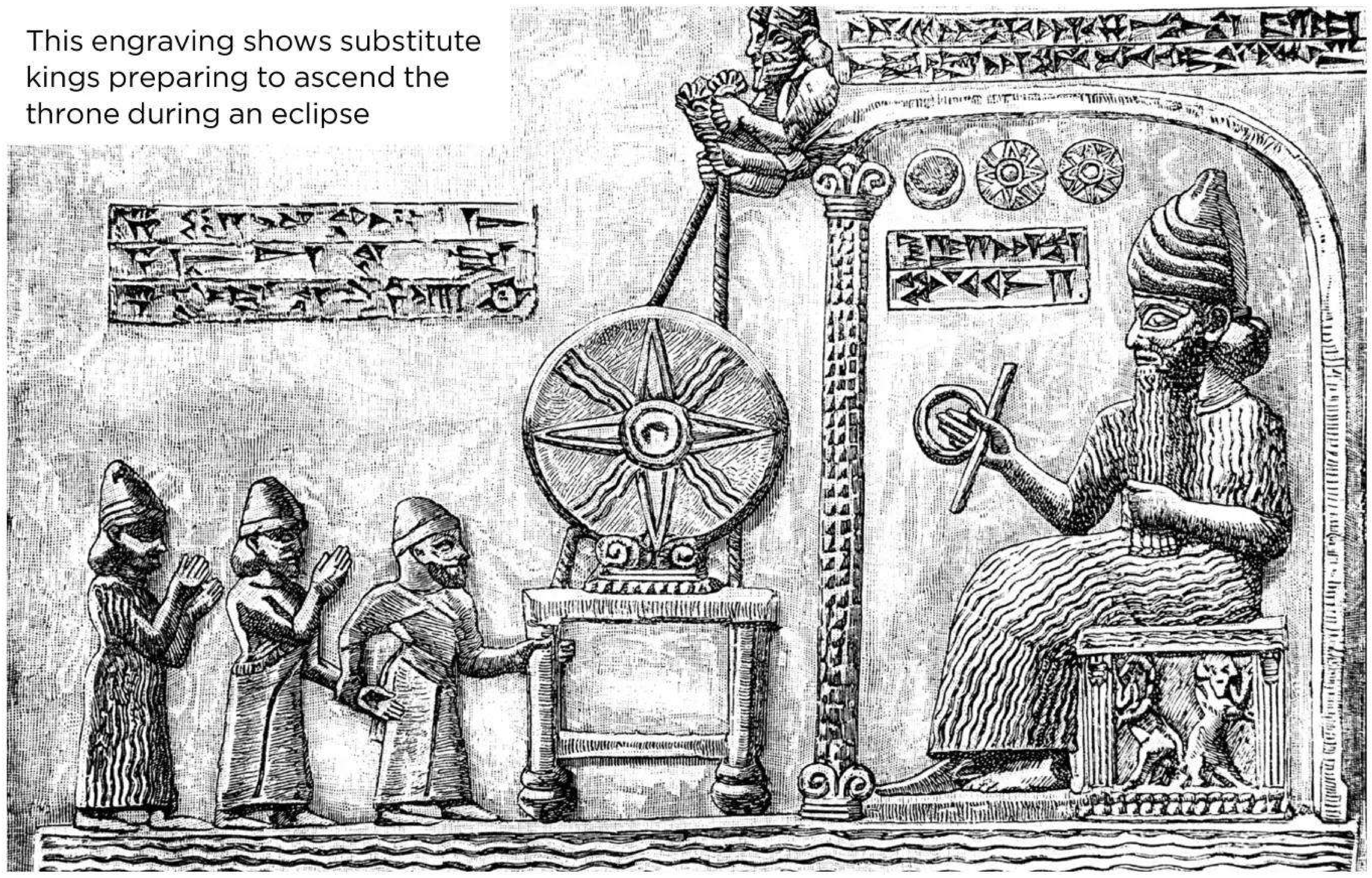
Such rituals demonstrate how closely linked Babylonian astronomy and astrology were. With much less scientific knowledge to base their beliefs on, ancient civilisations like Babylonia combined religion and science. Though they could make extremely accurate observations to determine what was happening in the cosmos, they lacked the technology required to find out why the heavens move as they do. As with all time periods, humans could only anticipate the facts using the information available.

THE SAROS CYCLE

The path to predicting eclipse phenomena was one of patience and dedication. Babylonians analysed the time between each eclipse and eventually they were able to formulate the Saros cycle. They calculated that there could be 38 eclipses within a time frame of 223 months, which roughly equates to 18 years. All the eclipses that take place during this time period are part of a single Saros cycle.

After calculating the Saros cycle, within which the Sun, Moon and Earth were arranged close together, Babylonians multiplied this cycle by three. This period, which they analysed and named the 'triple Saros' (or exeligmos) covered 54 years. This was in an attempt to visualise any missed patterns in activity over a longer period. Considering long-term movements made their cycle and predictions more accurate.

Modern astronomers have since learned that this cycle isn't entirely accurate. This is because there aren't always the same number of eclipses in one Saros cycle. Yet this discovery does not detract from the Babylonians' impressive astronomical achievements. Regardless of its accuracy, formulating the Saros cycle was quite a feat of mathematics, and their calculations were accurate enough that their eclipse predictions proved fairly fruitful.



This engraving shows substitute kings preparing to ascend the throne during an eclipse

"THE SUBSTITUTE WAS TO BE KILLED AS A SACRIFICE TO KEEP THE REAL KING FROM HARM"

AN EXTENSIVE RECORD

To have access to enough data to predict such detailed events the Babylonians needed to keep records. This is something they did meticulously. For over 3,000 years they carved descriptions and depictions of celestial events into clay tablets.

The patterns drawn assisted them in future months and years to recognise the shapes presented to them by the stars and planets. Evidence shows that this ancient civilisation had worked out that eclipses occurred on a repeating cycle, yet they continued to interpret the events as warning signs from unhappy gods.

HOW DID THEY DECODE THE COSMOS?

Without the sophisticated technology of today, how would the ancient Babylonians track the precise movements of stars and planets across the sky? Thanks to their clay tablet descriptions, the more Babylonian artefacts that archaeologists uncover, the more we unveil about their resourceful work and mathematical minds. Their documented workings indicate that they used advanced mathematics, utilising Pythagoras' theorem over a thousand years before the polymath's birth.

Science historian Mathieu Ossendrijver spent 13 years studying Babylonian clay tablets that had trapezoid shapes engraved in various arrangements. By 2016 he had deciphered that the ancient astronomers had been trailing Jupiter's precise movements. The sides of these shapes were used to work out the speed of the planet's movements across the sky over the course of 60 days. Because planets are much closer to Earth than the surrounding stars, the stars could be used as reference points as Jupiter appeared to shift past them.

Just as their studies of eclipses aligned with their beliefs of the supreme gods' powers, Jupiter held high importance to the Babylonians. In 350 BCE, one of the main gods of ancient Babylonia was Marduk. Writings show that this god's sacred star was Jupiter.

Aspects of astronomy and astrology were seamlessly combined in Babylonian space research. Many of today's scientists uncover astronomical wonders purely to enhance our knowledge and expand the possibilities of space exploration, but the ancient practices that emerged millennia before coincided strongly with religion and personal beliefs.

Using the same celestial objects — and some similar mathematical models before they became common practice — the carved notes preserved over many generations tell us that although plenty has changed in the way people think and live, phenomena like eclipses are timeless marvels. And it seems that the Babylonians might have been right to fear them after all, for it's thought a double eclipse (whereby a lunar eclipse was followed by a solar eclipse) presaged King Cyrus the Great's army seizing Babylon in 539 BCE.

This is an example of an ancient astronomical calendar with detailed markings

NIGHTTIME ON THE NILE

Millennia of tracking the stars made the Egyptians masters of time

WORDS NIKOLE ROBINSON

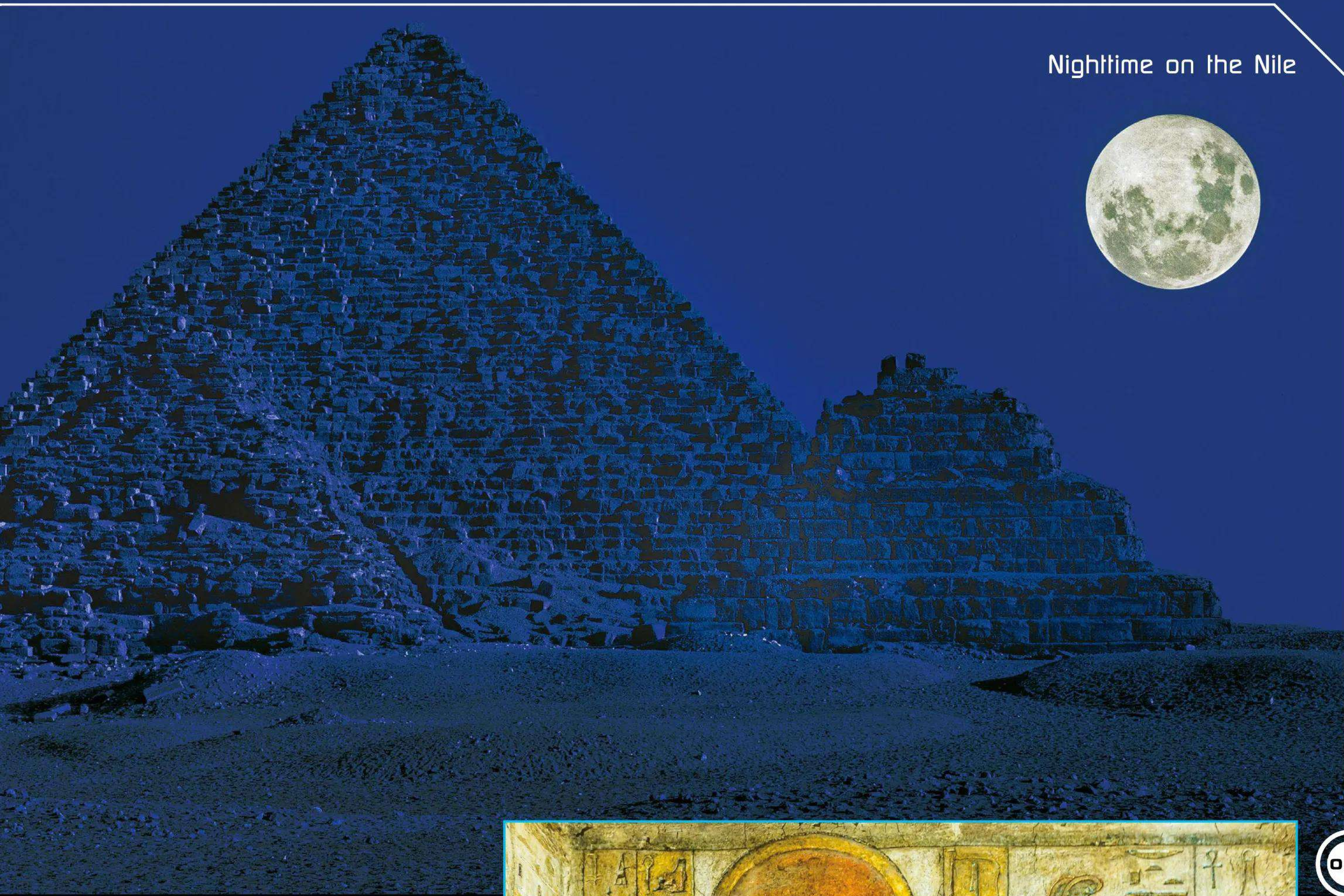
The Nabta Playa calendar circle is one of the earliest examples of timekeeping

Thousands of years before the rise of the pharaohs, nomads to the south realised the sky changed with the passing of time and that this was cyclical. They noticed the reappearance of certain stars coincided with the changing seasons, allowing them to plan when to plant and harvest crops for a better yield — crucial in an arid environment. A stone circle unearthed at Nabta Playa is the earliest example of a calendar from the region. It denotes the summer solstice and with it the coming of monsoons. The megalith appears to have been aligned with the stars Arcturus, Sirius and Alpha Centauri during its use, with other stones potentially representing Orion's Belt.

By the Early Dynastic Period, around 3100 BCE, astronomical timekeeping had become much more refined. A new Moon represented the beginning of the month, of which there were 12 in a year. However, this required the addition of a 13th month every few years in order to stay aligned with the stars and the seasons.

By tracking the annual path of the Sun and noting how its position changed over time, ancient Egyptian scholars were able to determine that it made a full cycle every 365 days. This repetition would become the basis for a new civil calendar that followed the Sun, while the old lunar calendar was mainly used to plan religious festivals, of which there were many.

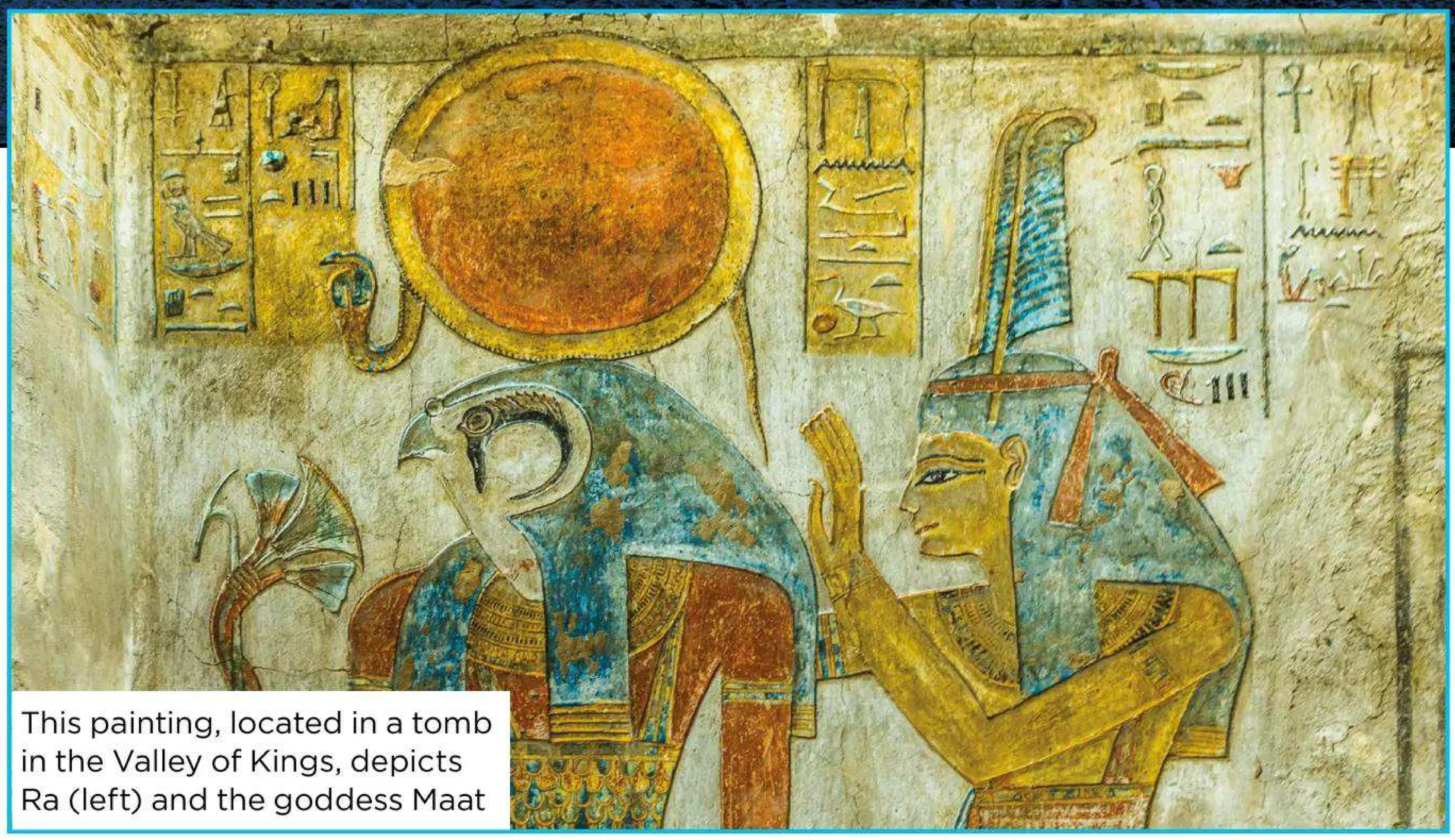
The Egyptian year was divided into three seasons, each with four months of 30 days, with a week lasting ten days. The start of the civil calendar was marked by the heliacal rising of Sirius, which the Egyptians called Sopdet and worshipped as a goddess, since its rising at dawn coincided with the annual flooding of the Nile. A festival called Wepet Renpet was held to celebrate this time of rebirth and rejuvenation. The first season was called Akhet and this was when seeds were planted. Peret followed and was known as the season of emergence after the growing crops. Finally, Shemu was a time of harvest.



With the three seasons making up 360 days, the remaining five 'epagomenal days' were days of jubilation spent celebrating another rotation of the sky. The time of day was known from the placement of the Sun's shadow, while in order to keep track of the passage of time at night ancient astronomers divided the night sky into 36 *decans* of constellations.

While the Egyptians were familiar with how the Sun, Moon and stars moved in cycles and were even aware of five of the planets, they believed this to be the work of the gods, who kept the world in order. Although there was a vast pantheon of gods who represented different natural and cosmic wonders, worship revolved around the Sun and its daily journey across the sky. Ra, the Sun god, rose to prominence as the giver of life. It was believed that he carried the Sun along its path in the sky, ferrying it safely through the underworld at night to rise again at dawn. Apep, the snake-like god of chaos, would attempt to stop him each night by swallowing the Sun. Prayers and offerings would be made in support of Ra, and each dawn represented his victory.

For a culture so focused on cosmic order and the power of the Sun, there is a surprising lack of documentation on solar eclipses, even in records from the Old Kingdom, where the Sun disc itself was worshipped as the Aten. Some historians believe that even the recording of these events would have been taboo, with the sky suddenly turning dark considered a bad omen. Those who witnessed an eclipse fearfully prayed that the Sun would return. Priests may have explained eclipses as Apep's temporary triumph over Ra, with the god being swallowed up by his nemesis before breaking free, tying the frightening events into existing mythos.



This painting, located in a tomb in the Valley of Kings, depicts Ra (left) and the goddess Maat

Other myths state that the left eye of Horus, the sky god, represented the Moon, and his right eye was the Sun. Stories tell how Set stole the god's lunar eye, which was later restored by Thoth. This could be based on the viewing of a lunar eclipse, with the Moon's change in colour depicted as a fight between gods. However, there is also little acknowledgement of lunar eclipses, even though it's likely that the Egyptians were astronomically advanced enough to track and predict both phenomena.

Perhaps they were seen as little more than short-but-scary disruptions to the natural order that was so revered, or maybe all records have been lost. Either way, what is clear is that this ancient culture had a firm grasp on time and space.

MAGIC IN THE MORMON STATE

The total lunar eclipse of 4 April 2015 unfolds near Tear Drop Arch in Monument Valley, Utah.

ASTRONOMY AT THE ACROPOLIS

Moving away from mythology, Greek astronomers began to unlock the true nature of the heavens

WORDS NIKOLE ROBINSON

The great philosophers of ancient Greece saw the skies above them in a new light, with the celestial bodies simply something else to quantify using mathematical equations. With each new observation and discovery the gap widened between theology and theory.

The stars had become a science, and ancient Greek astronomers would lay the groundwork for modern astronomy. But though scholars could see the universe beyond the gods and wanted to uncover its secrets, others still retained their faith in myth and legend.

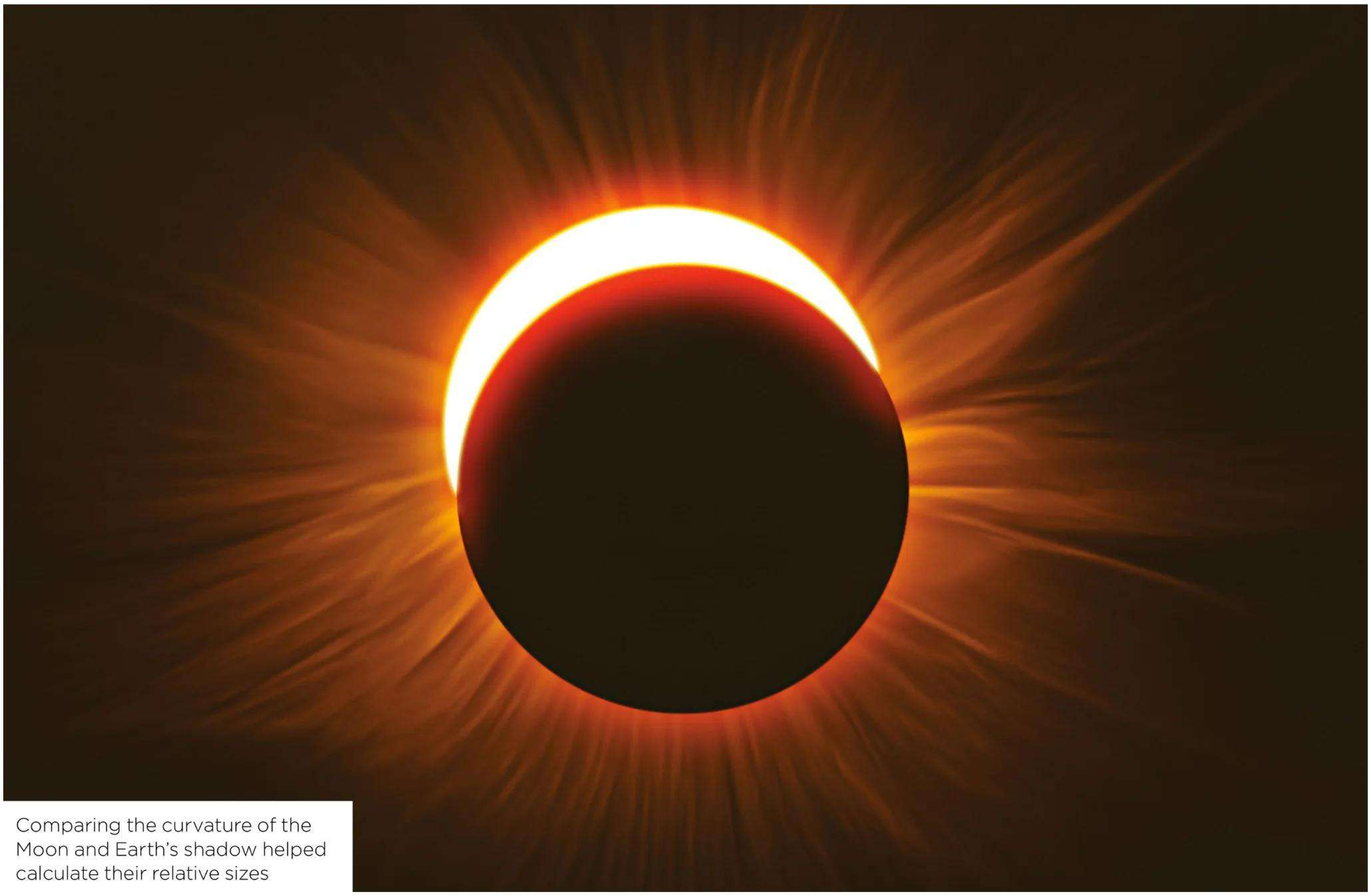
In the Greek pantheon, Helios was the personification of the Sun, flying across the sky from east to west each day in a flaming chariot drawn by winged horses. However, he held much less significance than the solar deities of previous cultures and was not worshipped heavily outside of Rhodes, where he was the patron god.

Celebrated even less was his sister, Selene, who represented the Moon. Their lower importance could be attributed to growing scientific understanding of the Sun and Moon, distancing them from the divine.

Though the Greeks got a lot right, they thought that Earth was at the centre of the universe

Eclipses have their place in mythology too, with solar eclipses in particular viewed as the gods turning their back on humanity. In fact, the word 'eclipse' is derived from the ancient Greek word for abandonment or disappearance. The most superstitious Greek kings saw eclipses as a warning of divine punishment; rulers would round up captives, dressing them up as decoy royalty until any perceived threat had passed before the prisoners were executed as a further precaution. Battles were also fought and halted with the observation of eclipses. In 585 BCE, the Lydians and Medes were in their sixth year of war when the sky suddenly darkened in the middle of the day. Seeing this as a terrible omen, both sides immediately sought to make peace.

In the early 5th century BCE, Anaxagoras was first to dispel the notion that eclipses were something to be feared, believing that they were simply part of the natural order of things. Viewing an eclipse in 463 BCE, he was able to come to the correct conclusion that the Moon was passing in front of the Sun, temporarily blocking its light from reaching Earth. This observation also confirmed his theory that the Moon did not produce its own light, instead reflecting the Sun's. Anaxagoras applied these principles to lunar eclipses, explaining that they were



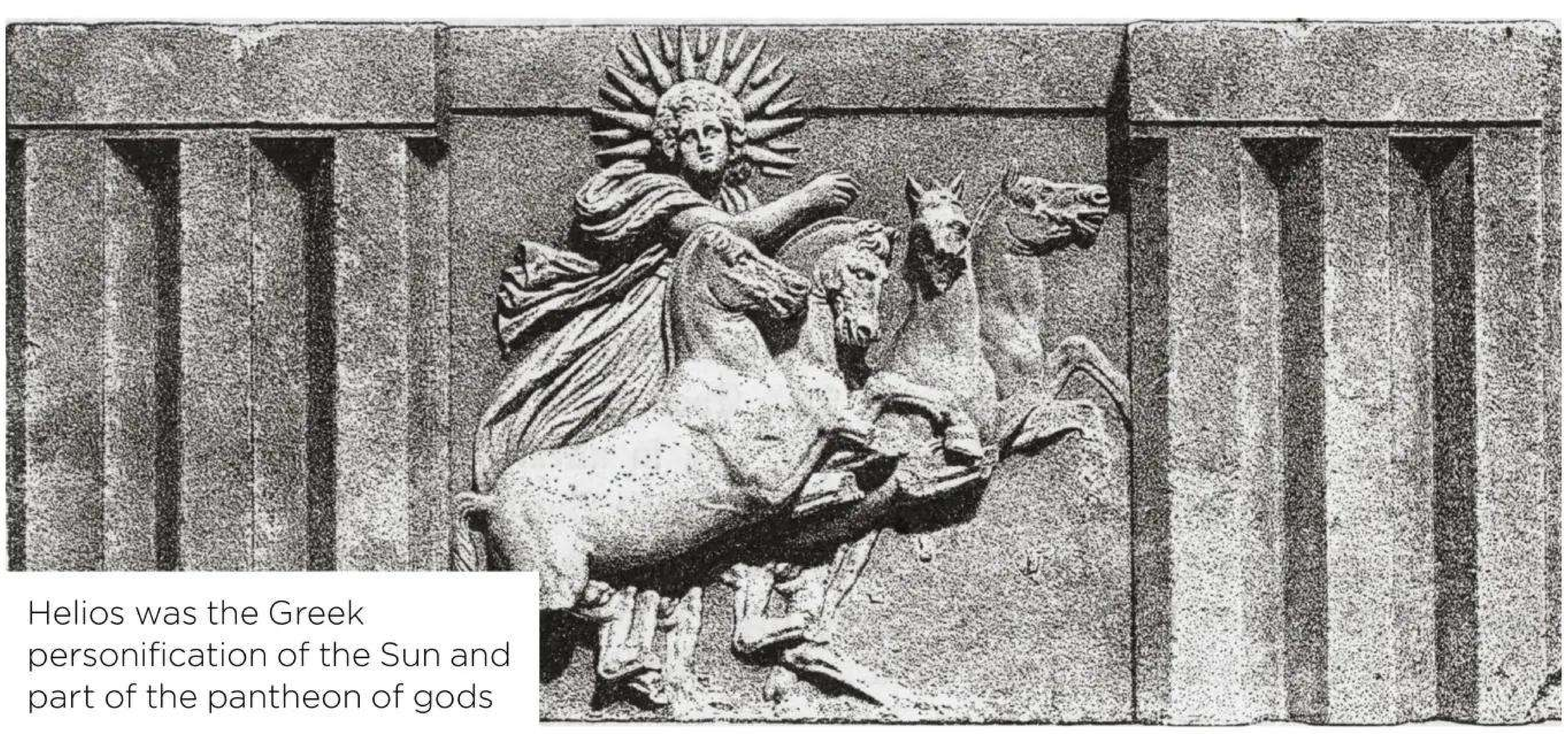
Comparing the curvature of the Moon and Earth's shadow helped calculate their relative sizes

caused by Earth's shadow falling across the Moon. With a scientific explanation in place, the astronomers of antiquity began to use these events as opportunities for research.

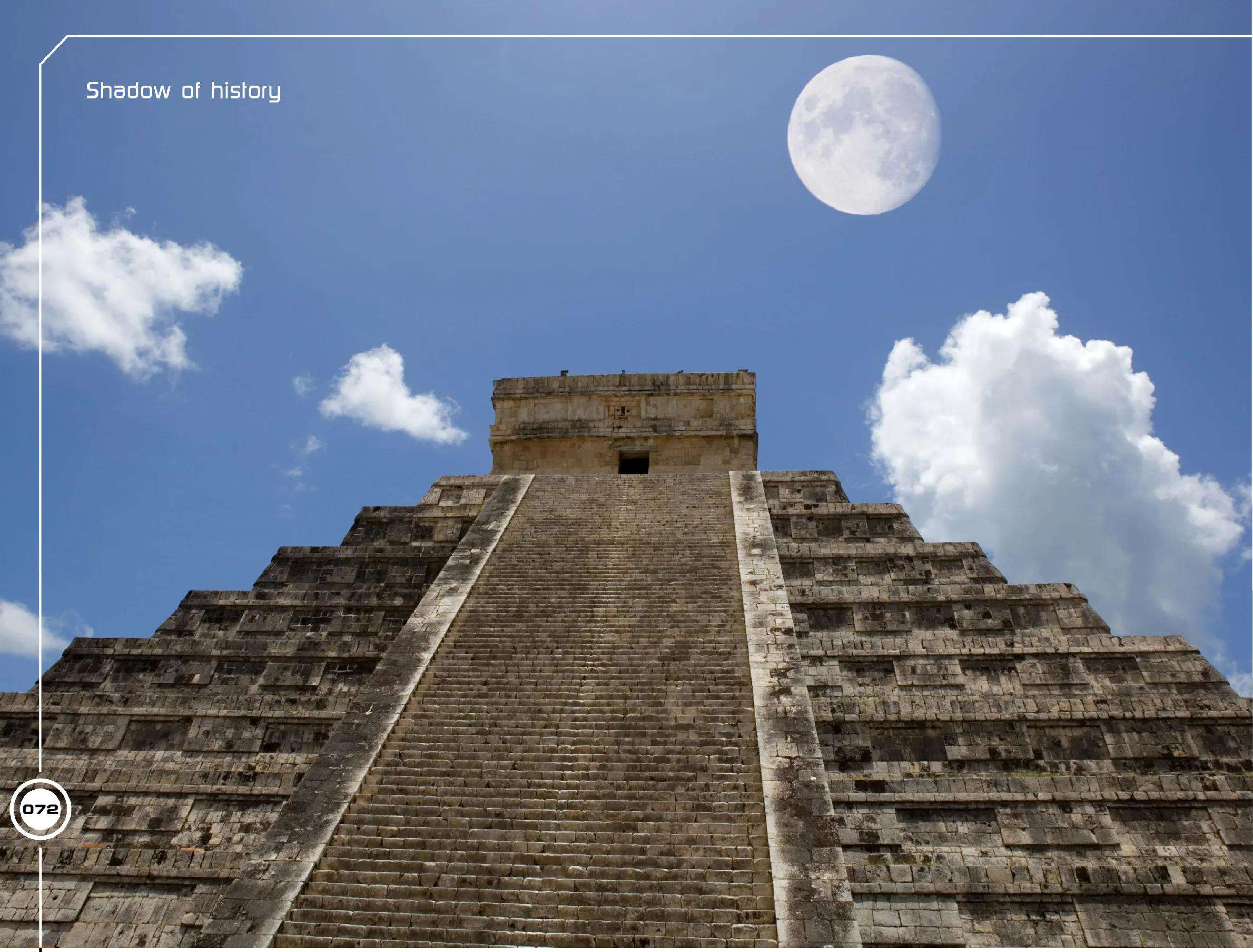
Aristotle used observations of partial lunar eclipses to confirm that the Earth was a sphere, a theory popularised by Pythagoras. Aware that the phenomenon was a result of Earth's shadow dimming moonlight, he noted that Earth's umbra appeared curved no matter where the Moon was in the sky at the time of an eclipse — something that could only be caused by the shadow of a spherical object. He validated this with the fact that when a person travels north or south, the constellations visible to them change. Another philosopher, Eratosthenes, realised that the angle of shadows also changed with a person's position on a spherical Earth. By equating the distance between two shadows on the summer solstice and measuring their relative angles, he was able to calculate the circumference of our planet — and he wasn't far off.

Around the same time, Aristarchus of Samos used geometry to work out the distances of the Sun and Moon and their sizes relative to Earth. After careful study of the size of Earth's shadow on the Moon during a lunar eclipse, he compared the curvature of the umbra to that of the Moon's disc and calculated that our satellite was about a third the size of our planet. Modern measurements show the Moon to be 27 per cent Earth's size, so his results were quite accurate for their time. His predictions of their distances, however, were not as precise. Thanks to solar eclipses, he knew that although the Moon and Sun appeared the same size, the Sun had to be further away in order to be blocked out. His calculations suggested that the distance to the Sun was 18 to 20 times the distance to the Moon, massively underestimating its true distance, which is 390 times further away than the Moon.

In studying the detailed astronomical records of the Babylonians and combining them with their own observations and calculations, by the time of Ptolemy the Greeks could accurately predict eclipses, planetary motion and many other celestial phenomena. The pioneering work of Greek astronomers would be continued by the Romans and the Islamic world, becoming a strong foundation on which many ideas were built and forever changing the way humanity viewed the heavens.



Helios was the Greek personification of the Sun and part of the pantheon of gods



INDIGENOUS ASTRONOMY

From the Maya and Aztecs of South America to the Aboriginals of Australia, indigenous people have been studying the skies for thousands of years

WORDS BEE GINGER

While the Greeks, Babylonians and Egyptians are all rightly credited for their groundbreaking studies of space, it should not be forgotten that there were many other ancient populations who spent much of their time trying to better understand the mysteries of the universe. The ancient Maya in particular were avid astronomers who interpreted and recorded every aspect of what they saw in the sky. By reading the planets, stars and Moon they believed they could interpret the actions and will of their gods. Not only did they dedicate many of their buildings to their studies and worship, they often planned life events to coincide with particular celestial moments. This included eclipses, but despite their entrancing nature, for the Maya these occasions inspired a sense of trepidation due to scary premonitions and myths.

Mexico's Yucatán Peninsula was once the heart of this great civilisation (and remains home for its descendants today). Boasting well-established astronomical traditions, the Maya were able to hone their knowledge of space in order to predict the astronomical cycles that result in eclipses. Their view of

"OUT OF THE BROKEN GROUND JAGUARS WOULD POUR FORTH TO DEVOUR EVERYTHING IN THEIR PATH"

eclipses, however, was shaped by fear, as the Maya (as well as many other Mesoamerican cultures) believed the event to be a harbinger of destruction, disease or drought in the region. Pregnant women were advised not to view the eclipse as it was believed to be detrimental to the health of their unborn baby, a myth that is still believed in large parts of the world today.

Many differing tales were believed by way of an explanation for the unique occurrence happening in the skies above. The Maya believed the other planets to be 'star demons' that ate away at the Moon and Sun during eclipses. Some of their stories and art work centred around these demons, which took the form of snakes and insects. The Lacandóns went further still, believing that the Earth would split as a result of an eclipse and out of the broken ground jaguars would pour forth to devour everything in their path.

At the commencement of an eclipse ancient Maya priests would begin their rituals by offering prayers to their gods asking to be spared from a world of darkness. These rituals could go on for several hours and included the lighting of incense and even the eating of snakes until the Sun would finally re-emerge and light and safety was once again restored. Sacrifice and prayer to the gods featured prominently in these attempts to appease the gods and prevent a cataclysm.

The Maya were committed to recording every aspect of history, including the weather and eclipses

AZTEC INTERPRETATIONS

The Maya weren't the only ones looking to the heavens from the jungles of South America. For the ancient Aztecs, an eclipse brought with it fears of the end of the world. Terrified that demons of darkness would destroy the Earth, they used rituals and blood sacrifices (both animal and human) in order to ward off any imminent disaster. They also believed the land of the dead was hidden beyond the Sun, a realm invisible to the naked eye due to the strong glare of our nearest star.

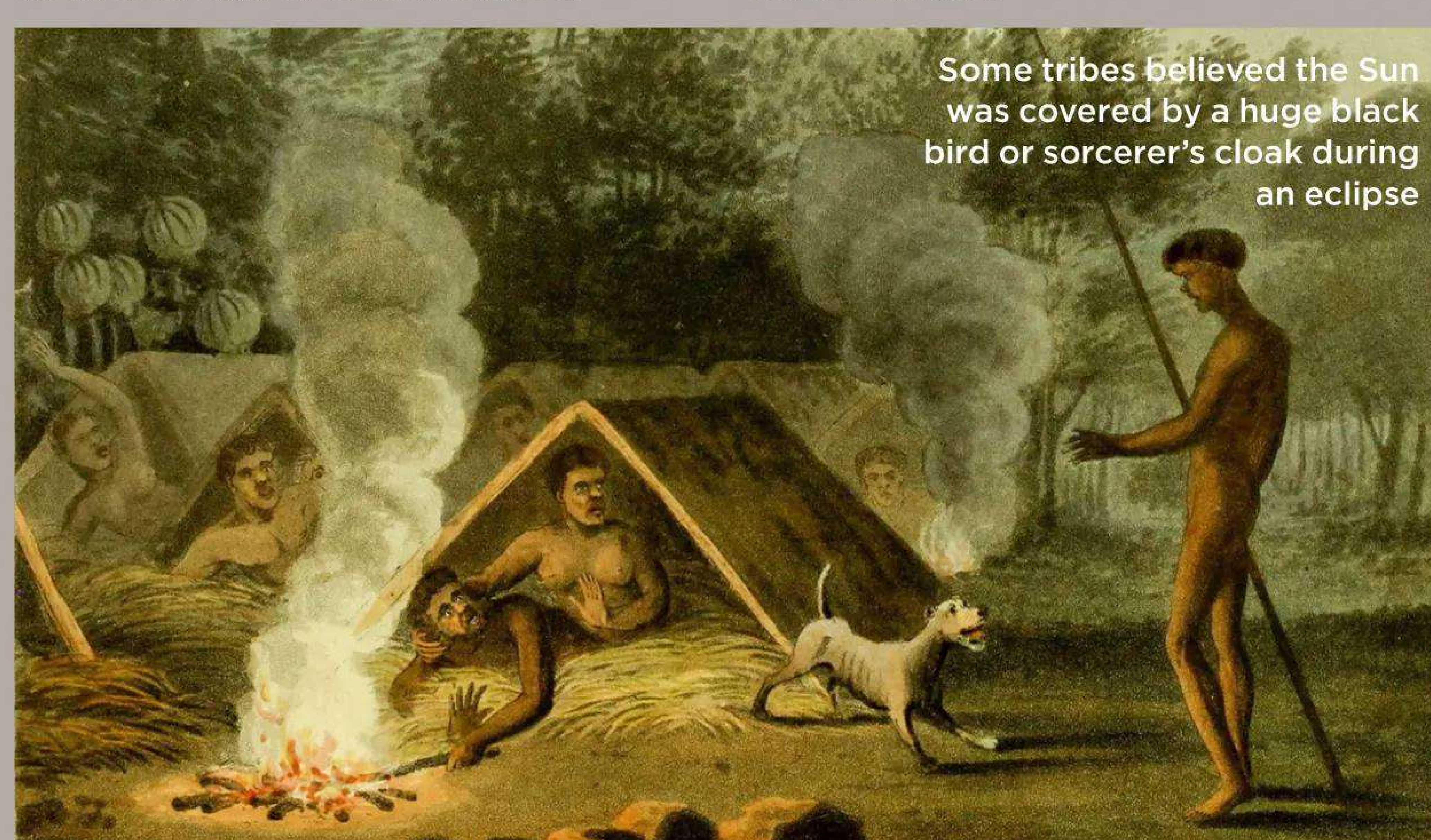
They also believed in Tzitzimime, skeletal creatures associated with stars. These were said to be the souls of sacrificed warriors. It was feared that these monstrous beings would consume the Sun before bringing an end to the known world. One date in the calendar year struck immense fear into the Aztecs: if on the date 4 Ollin (which repeated every 260 days on the Aztec calendar) a solar eclipse was accompanied by an earthquake then it would signify the end of the world.

Hewn from basalt between 1502 and 1520, the Aztec Sun stone weighs 24,590kg (54,211lb) and measures 3.6m (12ft) in diameter

ABORIGINAL STARGAZERS

Indigenous groups throughout Australia have used the motions of the stars, Sun and Moon to make sense of natural cycles for thousands of years. Their understanding of celestial movements was relatively sophisticated, however, the appearance of an eclipse would understandably still cause panic, with many Aboriginal communities seeing them as a sign of black magic or worse, impending doom. Disaster could only be prevented by a *wirreenun*, a type of weather or rain man who would chant at the eclipsing Sun or throw a boomerang or sacred stones at it.

In southeastern Australia many tribes believed that spirits held up the canopy of the sky and that the Sun's disappearance was a result of some sort of magic.



Some tribes believed the Sun was covered by a huge black bird or sorcerer's cloak during an eclipse

BIG SKY: HOW NATIVE AMERICANS TRACKED THE MOON

To the indigenous Native American tribes, eclipses hold many important cultural meanings

WORDS BEE GINGER

The phenomenon of an eclipse, be it total, annular or partial, marks a sacred moment in many people's lives. Remembering where you were and who you were with during a celestial alignment is a lasting memory. That moment of complete silence when everything around you is falls still and it feels like the Earth has momentarily stopped breathing is a profound experience, doubly so if you attribute a deeper meaning to the stars. The Native Americans certainly do. In fact their knowledge and appreciation of the cosmos shapes how they live.

Many Native Americans view eclipses as spiritual experiences. The Navajo, for example, look at the entire universe as being holistic. Therefore during an eclipse the Sun, Moon and Earth become aligned and interconnected in the cosmic order — a sacred natural phenomenon. They believe the Sun to be male and the Moon female. While the Moon is responsible for regulating and controlling the Earth, it is the responsibility of the Sun to do the same for the entire universe. This is because the Sun is the most powerful deity of all creation and without him nothing will survive. Therefore the Sun is said to be in control of death (anoonééł), leaving the Moon to be responsible for birth (oochííł).

Both lunar and solar eclipses take on enormous significance, as when one occurs it is believed that a death will coincide. An eclipse is seen as a renewal process, where all of creation and the whole universe are realigned and reborn, allowing for fresh growth and development ahead. When the Sun is obscured by the Moon it is experiencing a rebirth. This sacred celestial moment is a time for reflection and prayer, therefore you are not permitted to sleep, drink, eat or look at the eclipse. Interestingly, the Navajo link exposure to an eclipsed Sun to

The Apache and Navajo would use corn meal or pollen as an offering to the rising Sun and at the time of an eclipse

birth defects and mental and physical ailments. They will often cover their livestocks' food and water to prevent its exposure to the eclipse.

Many indigenous groups use the occasion of an eclipse to practice and pass on their cultural teachings to younger generations. Groups like the Modoc, Klamath and Yahooskin-Paiute do this through sharing stories related to the eclipse. One of the most intriguing is that of a grizzly bear intent on eating the Moon. As the bear commences his feast he is startled by a frog jumping on the Moon. The Moon promptly takes the frog as his wife so she can keep the bear away. Interestingly, the Sun also goes on to marry the frog for the same reason.

Many groups still call to the frog to come when an eclipse commences. Some stories, however, vary slightly in the details. The Cherokee believe there to be a giant frog in the sky, but it isn't our star's protector: it's trying to eat the Sun. The Cherokee will rush outside during an eclipse making an incredible racket with whistles, drums and voices in order to scare the frog away.

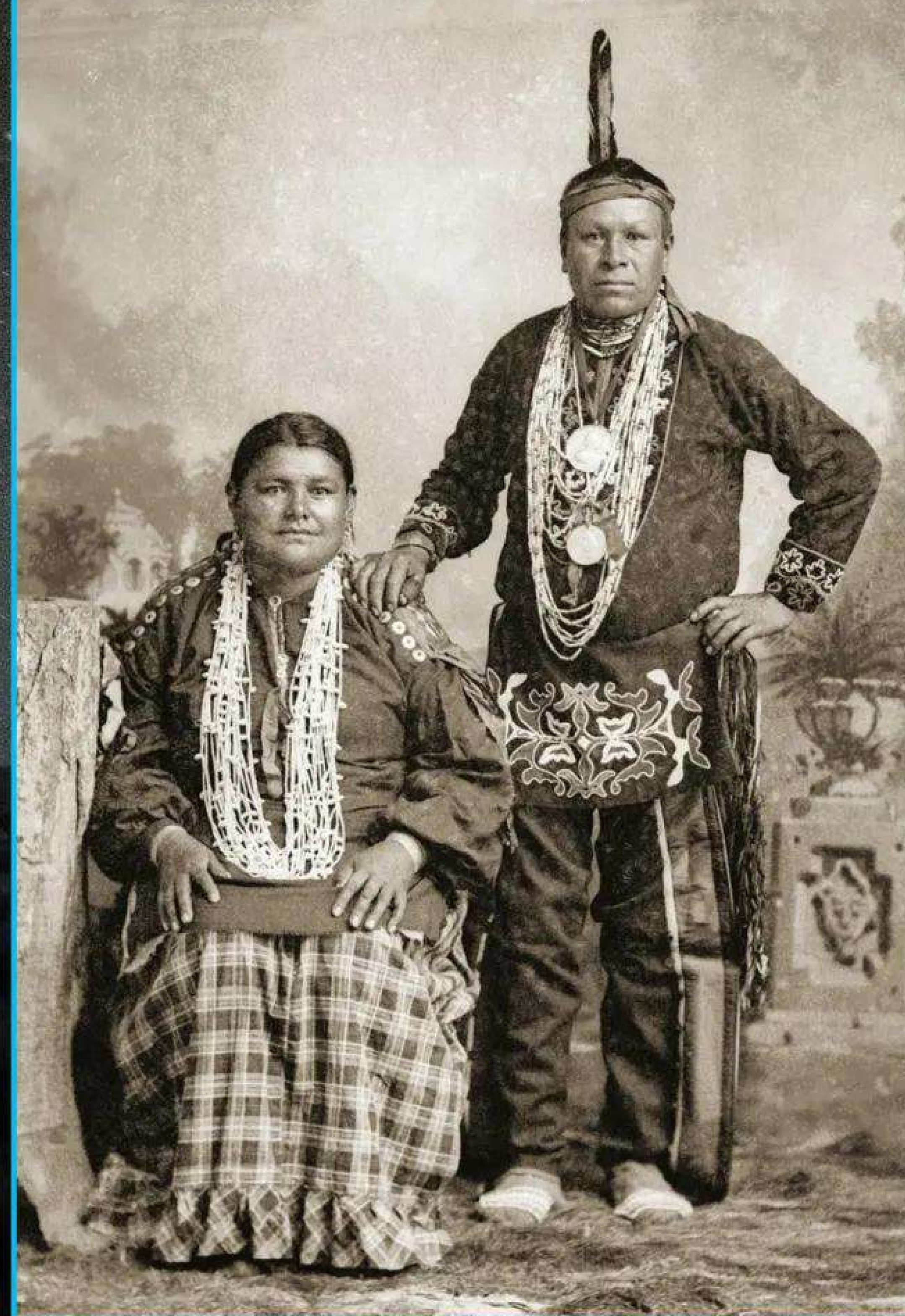
Some interpret an eclipse as an omen signifying an event that is yet to come to pass. The same applies to other lunar and meteor activity: all represent a natural occurrence about to happen on the Earth. One example is rings around the Moon or Sun, which can indicate a significant shift in the weather.

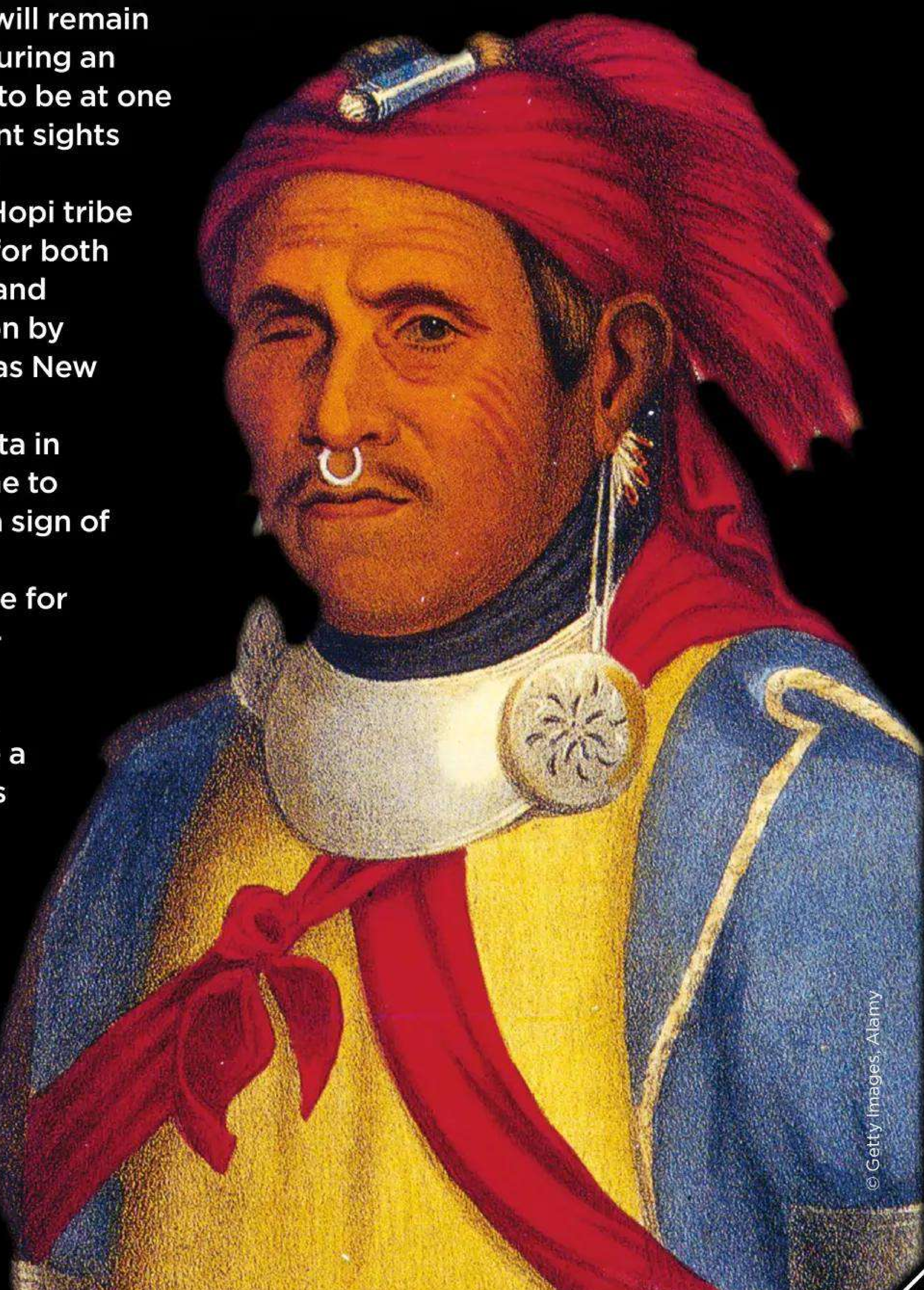
Although tribes remain united in the protection of their native land, each individual group has varying beliefs when it comes to eclipses. Even within the individual tribes some will have different rituals. Groups like the Navajo will remain home practising mindfulness during an eclipse, while others will strive to be at one with nature or venture to ancient sights armed with eclipse glasses and anticipation for the reset. The Hopi tribe use the time during an eclipse for both prayer to their Sun god, Tawa, and ceremony, marking the occasion by bestowing sacred names such as New Colourful Sun on children.

The Stoney Nakoda of Alberta in Canada use the eclipse as a time to prepare, believing them to be a sign of omens and imminent change.

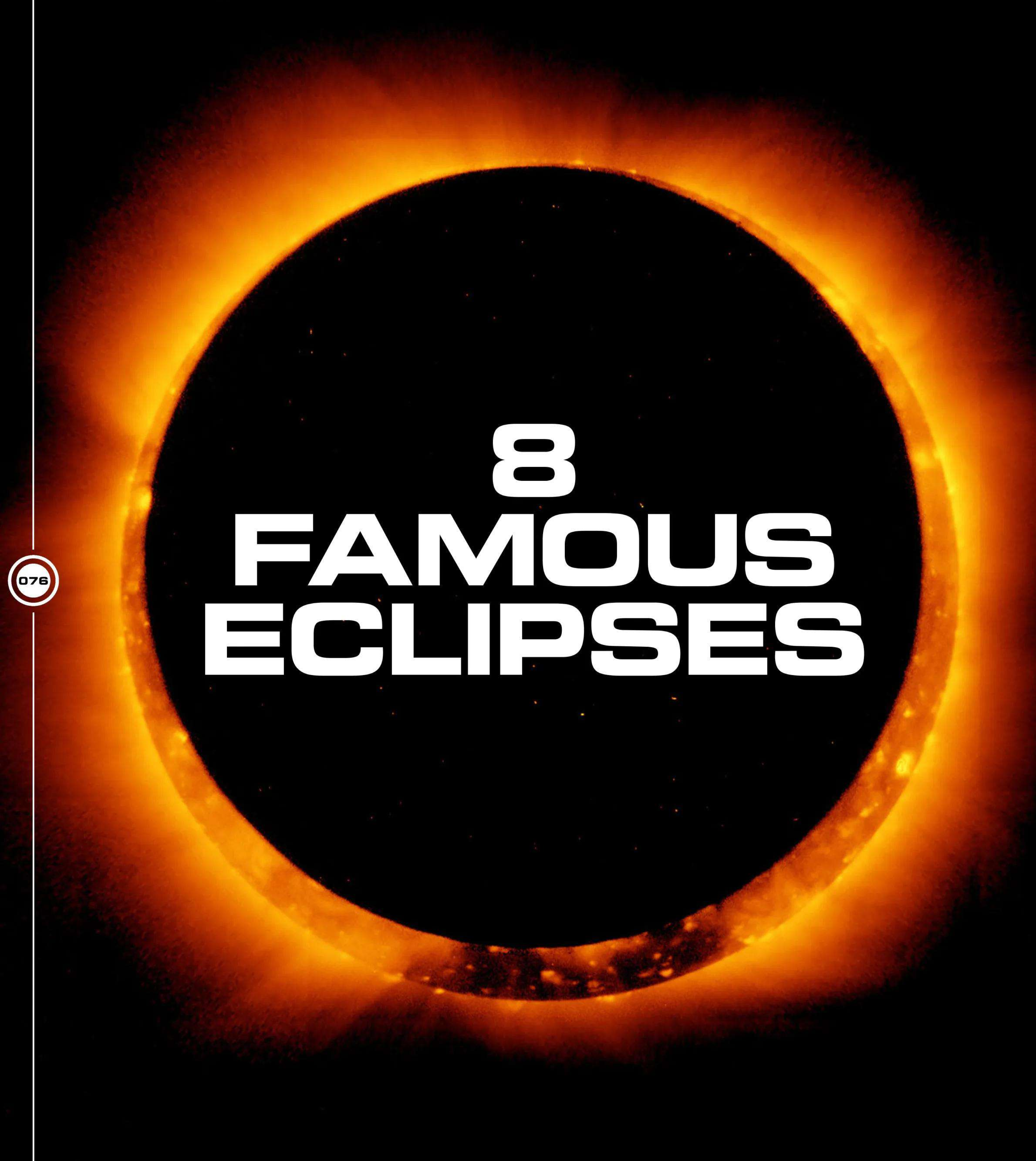
Perhaps there is a lesson here for society. It is evident in this fast-paced world that many people have lost their connection with nature. We'd all be wise to take a moment away from our screens and look up at the sky. You never know what it could be trying to tell you.

The Ho-Chunk believe all eclipses are to be respected, as it is during an eclipse that transformation takes place





RIGHT: Asked to prove he could predict the future, Tenskwatawa (known as 'the prophet') of the Shawnee tribe correctly warned of a coming solar eclipse in 1812



8 FAMOUS ECLIPSES

Since ancient times, people have viewed eclipses as omens of a miracle – or disaster

WORDS TIA GHOSE

From the earliest recorded eclipses described on an ancient clay tablet in Ugarit in modern-day Syria to one that was linked to an uprising in an ancient Assyrian city and another that proved a fundamental scientific theory in the 20th century, here are some of the most famous eclipses ever seen.

GREAT AMERICAN TOTAL SOLAR ECLIPSE

The first total solar eclipse visible in the United States in nearly four decades dazzled on 21 August 2017. During the so-called Great American Total Solar Eclipse, the 110-kilometre-wide (70-mile) shadow cast by the Moon darkened skies from Oregon to South Carolina, according to **Space.com**.

During most solar eclipses the Moon takes just a 'bite' out of the Sun, resulting in what is called a partial solar eclipse. It's rare to be able to observe this type of eclipse because the path of most total eclipses falls over water or unpopulated regions of the planet. The August event went down as the first total solar eclipse whose path of totality stayed completely in the United States since 1776.

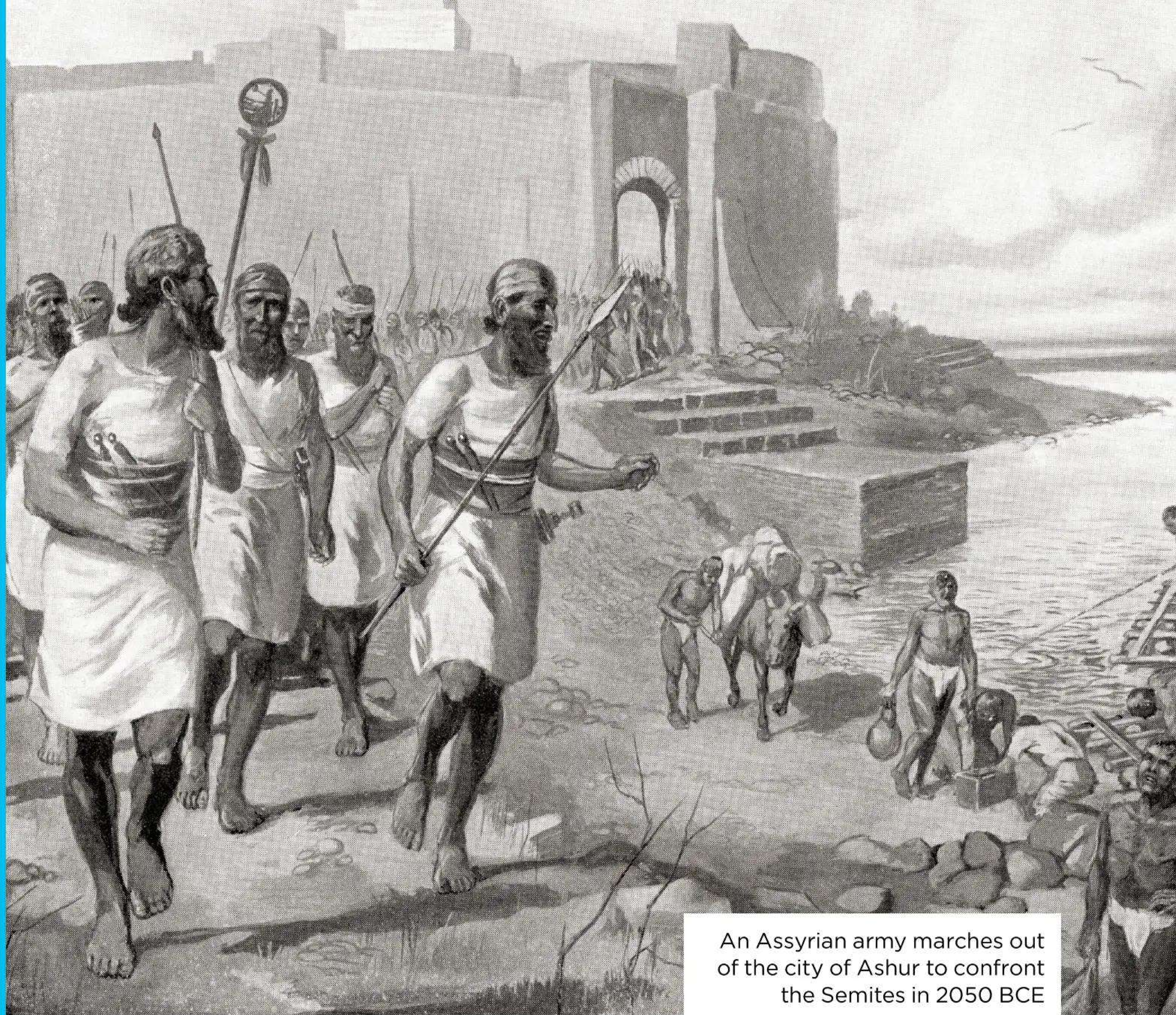
2 UGARIT ECLIPSE

One of the earliest solar eclipses recorded, the Ugarit eclipse darkened the sky for two minutes and seven seconds on 3 May 1375 BCE, according to an analysis of a clay tablet that was discovered in 1948. However, a report in the journal *Nature* in 1989 suggested the eclipse actually occurred on 5 March 1223 BCE. That new date was based on a historical dating of the tablet as well as an analysis of the tablet's text, which mentions the visibility of the planet Mars during the eclipse. Mesopotamian historians in Ugarit, a port city in northern Syria, recounted that the Sun was "put to shame" during this total eclipse.

The Sun sets over the ruins of Ugarit, which was abandoned in 6000 BCE and discovered in 1928

3 CRUCIFIXION OF JESUS

The Christian gospels say that the sky was darkened for hours after the crucifixion of Jesus, which historians viewed either as a miracle or a portent of dark times to come. Later historians used astronomy to pinpoint the death of Christ based on this eclipse mention. Some historians tie the crucifixion to a total solar eclipse lasting one minute and 59 seconds that occurred in the year 29 CE; others say a second total eclipse that blocked the Sun for over four minutes in 33 CE marked Jesus' death.



An Assyrian army marches out of the city of Ashur to confront the Semites in 2050 BCE

4 ASSYRIAN ECLIPSE

In 763 BCE., the Assyrian Empire, which occupied what is now Iraq, the Sun was completely eclipsed for five minutes. Early records from the period mention the eclipse in the same passage as an insurrection in the city of Ashur, now known as Qal'at Sherqat in Iraq, suggesting that the ancient people linked the two in their minds.

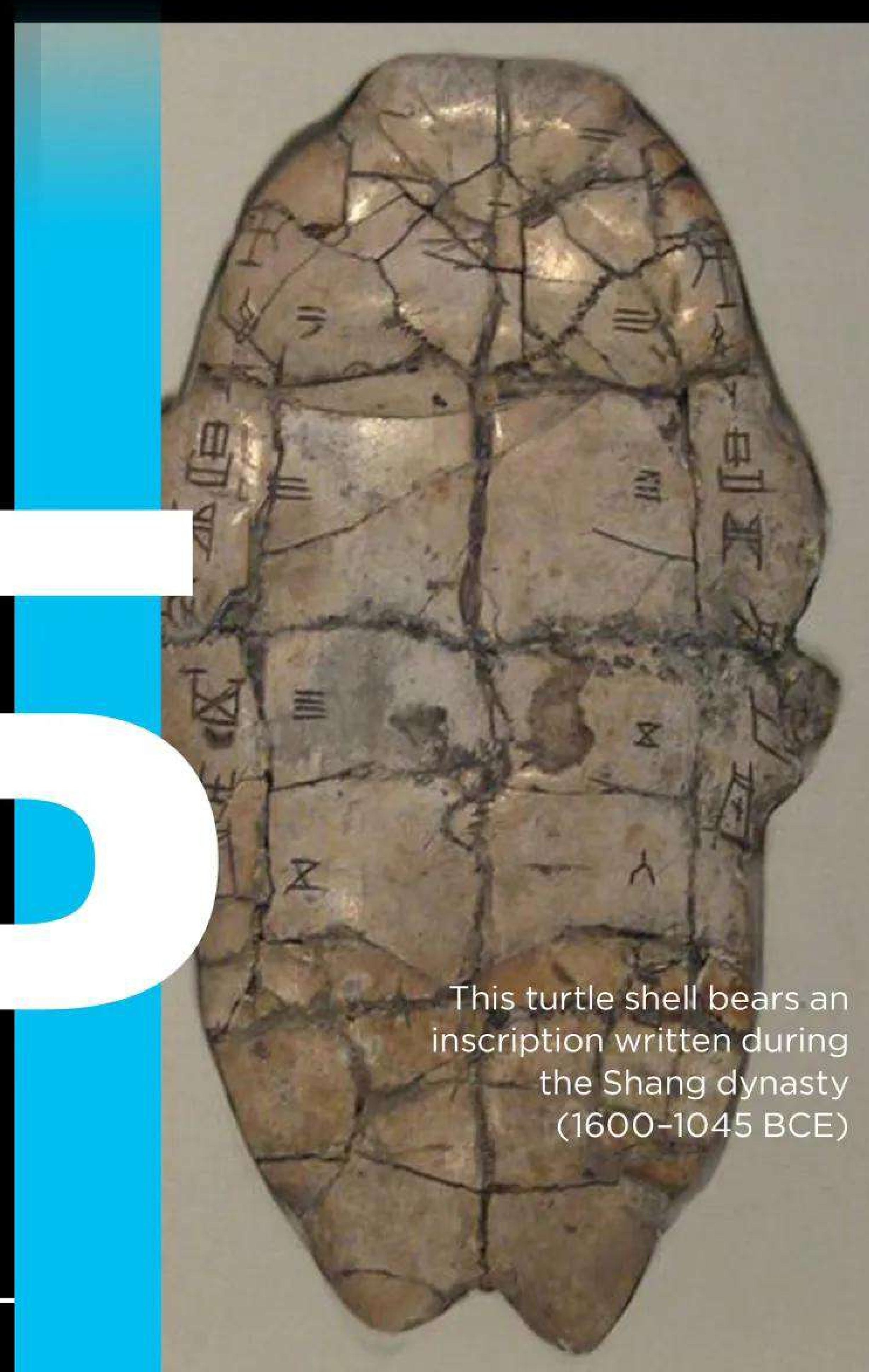
5 EARLY CHINESE ECLIPSE

In 1302 BCE, Chinese historians documented an epic total eclipse that blocked out the Sun for six minutes and 25 seconds. Because the Sun was a symbol of the emperor, an eclipse was seen as a warning to the ruler. After an eclipse, an emperor would eat vegetarian meals and perform rituals to rescue the Sun, according to a 2003 study in the *Journal of Astronomical History and Heritage*.

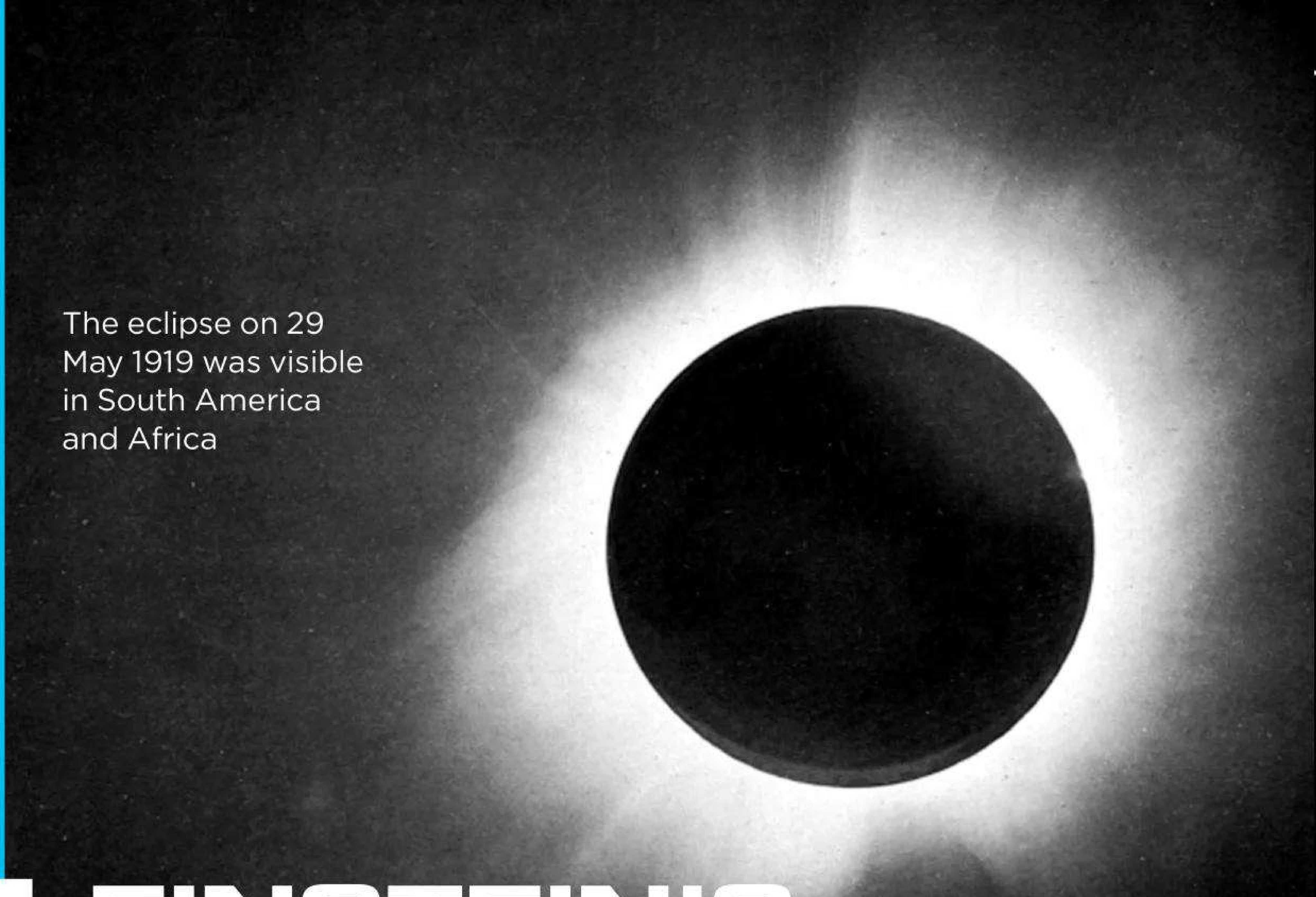
Kevin D. Pang, an astronomer at NASA's Jet Propulsion Laboratory, and colleagues analysed inscriptions on ancient turtle shell fragments (called oracle bones) to figure out the date of the eclipse — 5 June 1302 BCE. Part of the inscription reads, "Diviner Ko asks if the following day would be sunny or not," said NASA.

On the reverse side of the fragment, the inscription continued: "... 52nd day, fog until next dawn. Three flames ate the Sun, and big stars were seen."

Pang interpreted "three flames" as "coronal streamers licking out from the Sun's surface, visible only during total eclipses," said NASA.



This turtle shell bears an inscription written during the Shang dynasty (1600–1045 BCE)



The eclipse on 29 May 1919 was visible in South America and Africa

6 EINSTEIN'S ECLIPSE

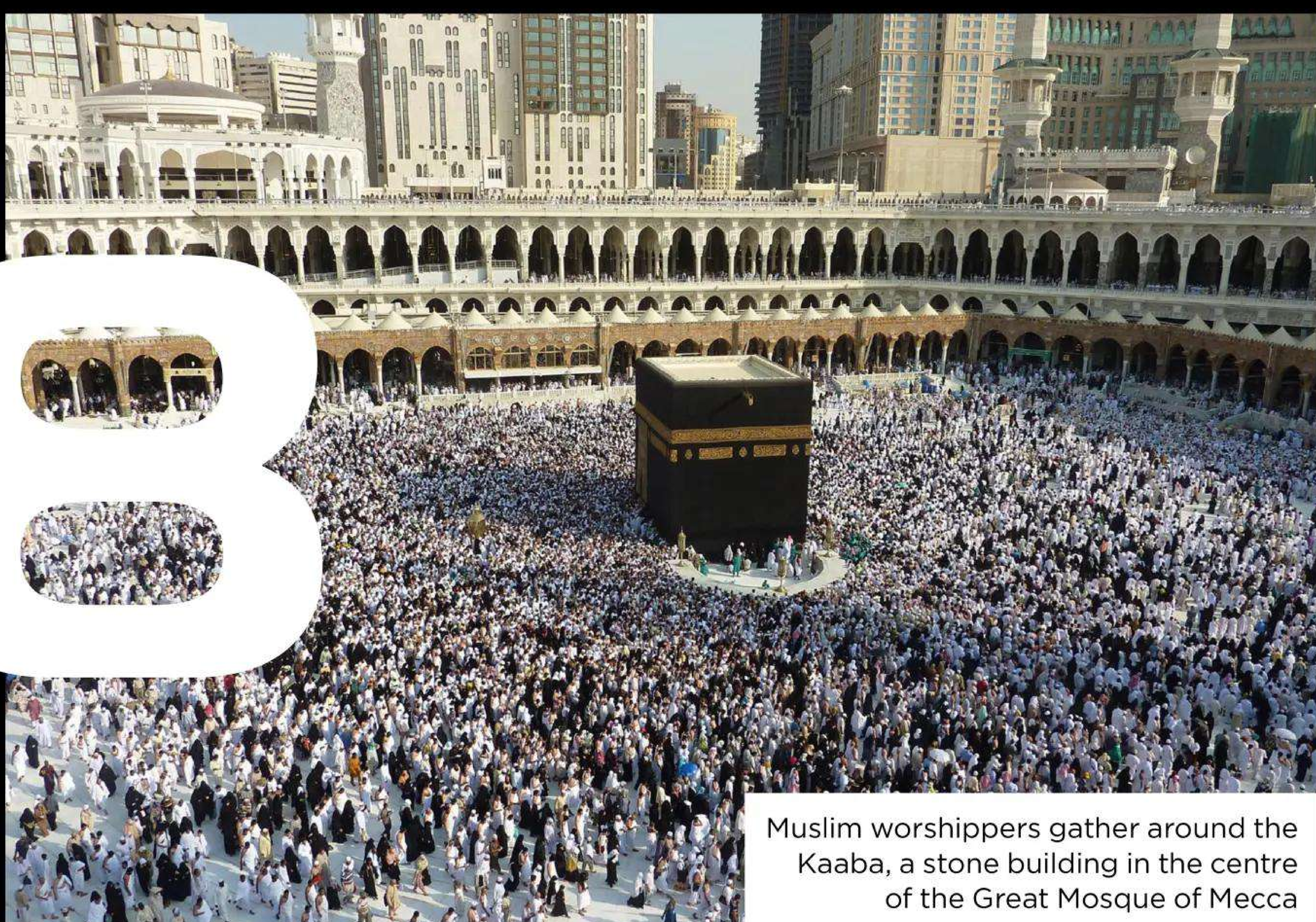
While the ancients viewed eclipses as signs of great acts of God, physicists viewed the 1919 solar eclipse as a triumph of science. During 1919's epic eclipse, in which the Sun vanished for six minutes and 51 seconds, scientists measured the bending of light from the stars as they passed near the Sun. The findings confirmed Einstein's theory of general relativity, which describes gravity as a warping of space-time.

7 KING HENRY'S ECLIPSE

When King Henry I of England, the son of William the Conqueror, died in 1133 CE, the event coincided with a total solar eclipse that lasted four minutes and 38 seconds. In the manuscript *Historia Novella,* William of Malmesbury recounts that the "hideous darkness" agitated the hearts of men. After the death, a struggle for the throne saw the kingdom descend into an 18-year civil war known as The Anarchy.

In the *Anglo-Saxon Chronicle*, a passage also recounts this eclipse: "In this year King Henry went over sea at Lammas, and the second day as he lay and slept on the ship the day darkened over all lands; and the Sun became as it were a three-night-old Moon, and the stars about it at mid-day. Men were greatly wonder-stricken and were affrighted, and said that a great thing should come thereafter. So it did, for the same year the king died on the following day after St Andrew's Mass-day, Dec 2 in Normandy."

King Stephen is captured at the Battle of Lincoln in 1141 during The Anarchy

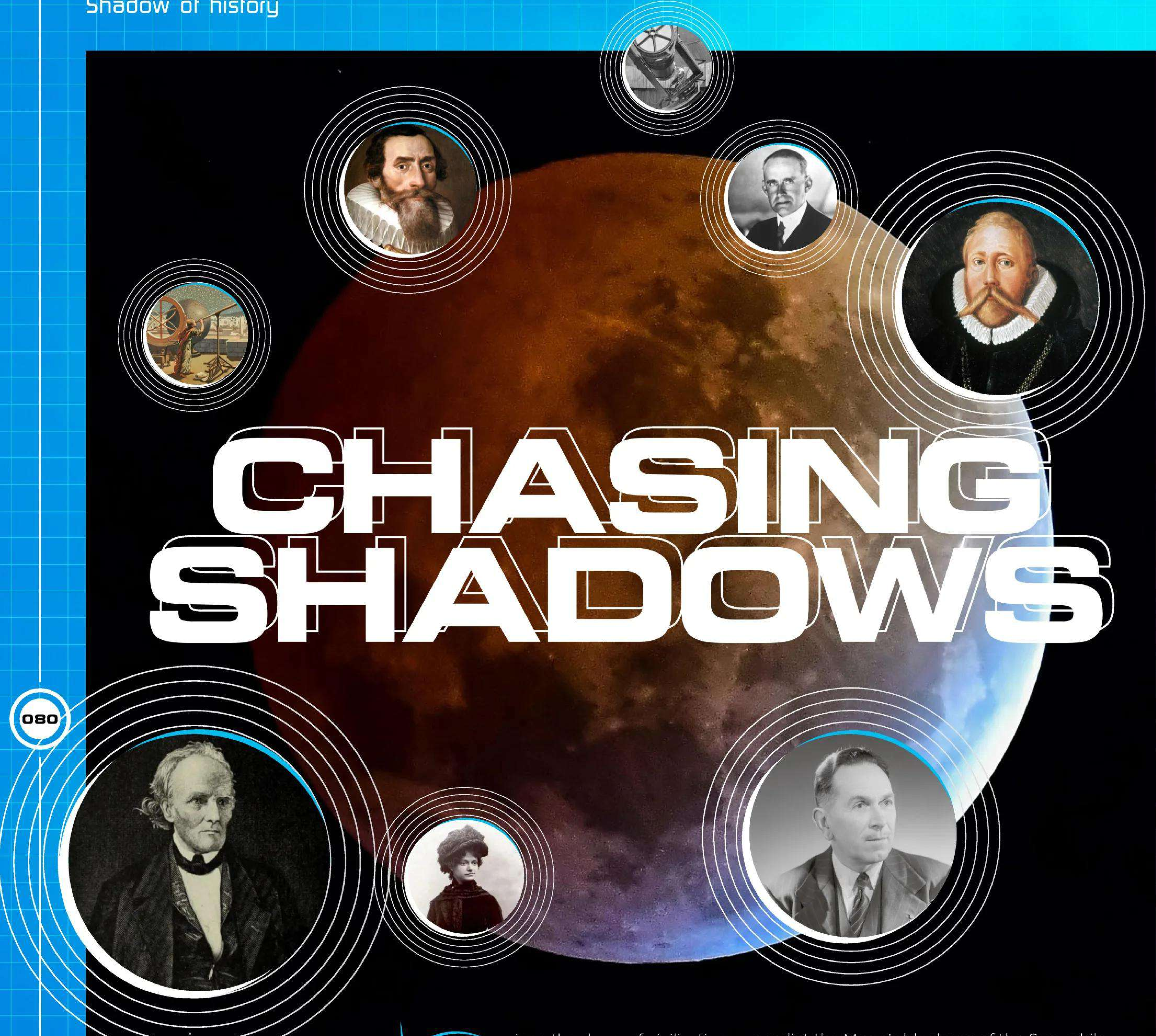


Muslim worshippers gather around the Kaaba, a stone building in the centre of the Great Mosque of Mecca

8 BIRTH OF MUHAMMAD

The Quran mentions an eclipse that preceded the birth of the prophet Muhammad, who was born in Mecca. Historians later tied this to a total eclipse that lasted three minutes and 17 seconds in 569 CE. The Sun also disappeared for one minute and 40 seconds on 27 January 632 CE after the death of Muhammad's son Ibrahim, who tragically passed away from an illness at just two years old.

However, the world's first Muslims didn't believe that this eclipse was a sign from God. Instead, according to Islamic texts called the Hadiths, Muhammad proclaimed "the Sun and the Moon do not suffer eclipse for any one's death or life".



CHASING SHADOWS

These dedicated stargazers were studying eclipses long before NASA even existed

WORDS NEIL CROSSLEY

Since the dawn of civilisation, humans have been awe-struck by the dramatic impact of solar and lunar eclipses, celestial events that drastically alter the appearance of the Sun and the Moon.

Most of us learn from an early age that a solar eclipse occurs when the Moon travels in between the Earth and the Sun, and a lunar eclipse is the result of the Earth travelling between the Moon and the Sun. But for millennia these events baffled, terrified and captivated whole civilisations.

In truth, a few pioneering astronomers from the ancient world understood the broad concepts and scientific models behind eclipses. Records suggest the Maya could predict the Moon's blockage of the Sun, while the astronomical observations and mathematical techniques of the Babylonians and ancient Greeks were fundamental in shaping scientific understanding. By 20 BCE, Chinese astronomers certainly understood that the Moon passed between the Sun and the Earth.

These ingenious thinkers laid the foundations for the scientific study of eclipses. In the centuries and millennia that followed, numerous astronomers, mathematicians and non-scientists would follow in their wake. But eight individuals in particular — some of the finest minds of their respective generations — would prove pivotal to our understanding of these natural and overwhelmingly thrilling phenomena.

NATIONALITY: GREEK

190 BCE–120 BCE

HIPPARCHUS OF NICAEA

Considered by many to be the greatest astronomer of classical antiquity, Hipparchus was also a geographer and mathematician, one best known for his incidental discovery of the precession of the equinoxes. By comparing his notes and mathematical techniques with previous observers, such as Meton of Athens in the 5th century BCE, he deduced that the points of solstice and equinox moved slowly from east to west against the fixed background of the stars.

Hipparchus also demonstrated that lunar eclipses can occur five months apart and solar eclipses occur seven months apart. He was the founder of trigonometry and combined his solar and lunar theories with trigonometric tables to develop a reliable method to predict eclipses.

Hipparchus recorded astronomical observations from 147 to 127 BCE and it seems likely that he invented the planispheric astrolabe, an astronomical device on which the celestial sphere is projected onto the plane of the equator.

According to the Roman author Pliny the Elder, Hipparchus discovered that "the shadow causing the eclipse must from sunrise onward be below the Earth... it happened once in the past that the Moon was eclipsed in the west while both luminaries were visible above the Earth".

Hipparchus was referring to the large total lunar eclipse of 26 November 139 BCE, viewed over "a clean sea horizon" from Rhodes, when the Moon was eclipsed in the northwest just after the Sun rose in the southeast.

DANISH

1546–1601

TYCHO BRAHE

On 21 August 1560, a 14-year-old Danish student called Tycho Brahe witnessed an event that would ignite his senses and define his life. The event was a total eclipse of the Sun, and the fact that this had been accurately predicted inspired Brahe to make astronomy his life's work. He would go on to transform the way that scientists viewed the cosmos.

A nobleman, Brahe wanted to study science so that he could learn how to predict eclipses. He studied mathematics and astronomy in Germany, and in 1571 he built his own observatory on an estate on the island of Hven, which had been given to him by King Frederick II of Denmark.

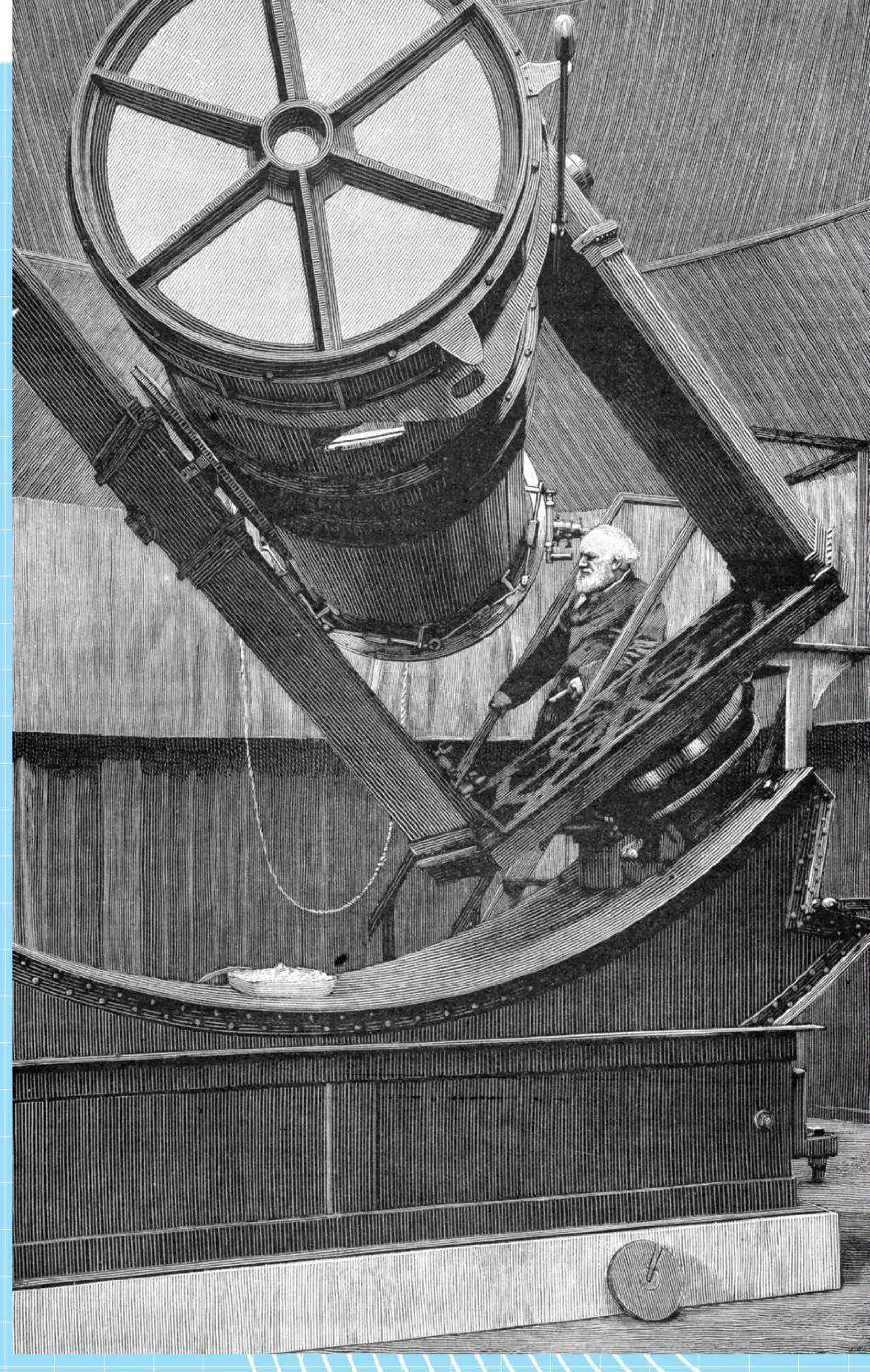
Brahe's primary goal was to determine the positions of the stars and planets as accurately as possible. He recorded meticulous observations using various instruments he constructed. But this work was relatively meaningless without someone to make sense of his measurements. That person would be Johannes Kepler, who in 1600 became apprenticed to Brahe when he was living in Prague after being exiled by the Danish king. Brahe died one year later, but Kepler's work drew directly on the meticulous observations of his former mentor, who was the last major astronomer to die before the invention of the telescope.

Brahe had led a colourful life. Arrogant and impulsive, he lost half his nose in a drunken duel with his cousin in 1566. He spent the rest of his life wearing various gold prostheses and is sometimes referred to as 'the man with the golden nose'.

FRENCH

1824–1907

PIERRE JULES CESAR JANSSEN



Born in Paris in 1824, Janssen spent his career observing eclipses and is responsible for some monumental discoveries.

In 1868, the French Academy of Sciences sent Janssen to India to observe a great solar eclipse, and it was on this expedition that he made his greatest finding. During the eclipse on 18 August, Jansenn observed bright lines in the spectrum of the chromosphere, the second-most outer layer of the Sun. These lines indicated that the chromosphere is gaseous. His theory was borne out at 10 a.m. the following day when he noted a yellow spectral line near the prominent lines of sodium. This line was the gas that would later be named helium but which would not be observed on Earth until 1895. It marked the first time that a chemical element was discovered on an extraterrestrial body before it was found on Earth.

On 19 September 1868, Janssen announced his discovery to the French Academy, but the news took two months to reach Europe. By then English astronomer Sir Joseph Norman Lockyer had also reported the same findings. It was Lockyer who would name the gas helium, from the Greek word *helios*, meaning Sun. In 1892, the French Academy named Janssen and Lockyer as co-discoverers.

GERMAN

1571–1630

JOHANNES KEPLER

When Johannes Kepler was nine his father took him to observe a lunar eclipse. The event had a profound impact on the future mathematician and astronomer and propelled him towards a life of celestial study.

Kepler laid the foundations for how we understand solar eclipses today. Empowered by access to Tycho Brahe's observations while working as his apprentice, Kepler gained a detailed understanding of how the planets moved, and he used mathematics to describe the motions of the planets orbiting around the Sun in his Three Laws of planetary motion.

Kepler's First Law states that planets move in elliptical paths around the Sun, while his Second Law concludes that planets move proportionally faster in their orbits when they are closer to the Sun. Kepler's Third Law explained the relationship between the distance of a planet from the Sun and the amount of time it took to orbit the Sun.

These three laws helped calculate distance, speed, time and mass and enabled scientists to estimate when eclipses will take place.

On 19 October 1604, Kepler spotted the last supernova observed with the naked eye in the Milky Way. In fact he studied the dying star so extensively that it was named after him.

Before his death in 1630 Kepler wrote his own epitaph: "I measured the skies, now I measure the shadows. Skybound was the mind, the body rests in the earth."

AMERICAN

1743–1817

SAMUEL WILLIAMS

As solar eclipse viewings go, it didn't look promising. The first American expedition to view a total solar eclipse took place in the midst of the American Revolutionary War on 21 October 1780. The expedition was led by Samuel Williams, a Presbyterian minister and a lecturer at Harvard University.

A special immunity agreement was negotiated with the British to allow Williams and his fellow scientists to work unharmed during the conflict

There was huge anticipation. It was hoped the data gathered would help to finally measure longitude in America by computing the distance from Greenwich. Geographers and mariners had so far been thwarted in their efforts to do this.

Williams chose the island of Isleboro in Penobscot Bay, Maine, as the best location to view the total solar eclipse. At 11 a.m. on 21 October 1780, he and his team of three assistants and six students adjusted their telescopes and counted down to the total solar eclipse. But by 12.30 p.m., to their utter dismay, the Moon had drawn back before it completely eclipsed the Sun. Williams and his party had missed the total solar eclipse simply because their map was inaccurate.

History has laid this mistake squarely on Williams' shoulders, although the expedition wasn't a complete failure. Williams and his team recorded enough data to accurately calculate their exact longitude and latitude. In his accounts, Williams also described phenomena now known as Baily's beads, distinctive drops of sunlight that shine through the lunar landscape as it passes the Sun. As the name suggests, it was British astronomer Francis Baily who would ultimately take the credit for this discovery.

"TO THEIR DISMAY THE MOON HAD DRAWN BACK BEFORE IT ECLIPSED THE SUN. WILLIAMS AND HIS PARTY HAD MISSED THE TOTAL SOLAR ECLIPSE"

FRENCH

1897–1952

BERNARD LYOT

Ever since the mid-19th century, astronomers had been attempting to study the solar corona, or aura, when the Sun was not eclipsed. The major challenge was always that the light of the Sun is a million times that of the corona. All efforts were unsuccessful — until Bernard Lyot of the Meudon Observatory set about creating the optical conditions needed to eliminate the diffused sunlight.

Lyot earned a reputation for being an expert of polarised and monochromatic light. Throughout the 1930s he worked to perfect the coronagraph, an instrument he invented to observe the corona without having to wait for a solar eclipse. He also selected a site that optimised viewing conditions: Pic du Midi Observatory, 2,877 metres (9,439 feet) high in the Pyrenees.

It was an exceptionally good location, free of both air pollution and light, but at the time it had one major disadvantage: access to the peak required mountaineering skills and physical fitness, particularly in winter when reaching it was only possible via a long and arduous ski trek. Fortunately, Lyot was a keen sportsman and mountaineer.

Empowered by his new coronagraph and conditions that, after a fall of snow, resulted in stray sunlight being of no greater intensity than the light of the corona, Lyot succeeded in photographing the inner corona, using screens to block out diffracted light.

Lyot, who later served as president of the Société astronomique de France from 1945 to 1947, went on to be awarded the Gold Medal of the Royal Astronomical Society for his observations and photography of the solar corona in the absence of an eclipse. Sadly, he died young, suffering a heart attack while returning from an eclipse expedition in Sudan on 2 April 1952 at the age of 55.

AMERICAN

1856–1832

MABEL LOOMIS TODD

Although best known for editing and publishing three volumes of Emily Dickinson's poetry, American writer and editor Mabel Loomis Todd also wrote a seminal 1894 book on eclipses entitled *Total Eclipses of the Sun*.

Todd travelled to solar eclipses with her husband, the noted American astronomer and teacher David Peck Todd. She had a strong understanding of astronomy, and with her fine writing skills she edited many of her husband's scientific papers and joined him on expeditions. One critic described the book as a "stunning and illuminating guide to one of the most moving creaturely experiences to be had on Earth".

Todd's work encompassed high levels of scientific knowledge, but she had a poetic sensibility and a unique talent for making scientific knowledge accessible to all.

Todd highlighted the importance of the viewer protecting their eyes when observing an eclipse: "Eyes must be bandaged for ten or twelve minutes before total phase," she wrote, "that they may be acutely sensitive to the faintest ray from these airy yet stupendously extended streamers of an unknown light."

Todd also described solar eclipses in a way that was both informative and beautifully written. "Then out upon the darkness, gruesome but sublime, flashes the glory of the incomparable corona, a silvery, soft, unearthly light, with radiant streamers, stretching at times millions of uncomprehended miles into space, while the rosy, flaming protuberances skirt the black rim of the Moon in ethereal splendour. It becomes curiously cold, dew frequently forms, and the chill is perhaps mental as well as physical."

BRITISH

1882–1944

ARTHUR EDDINGTON

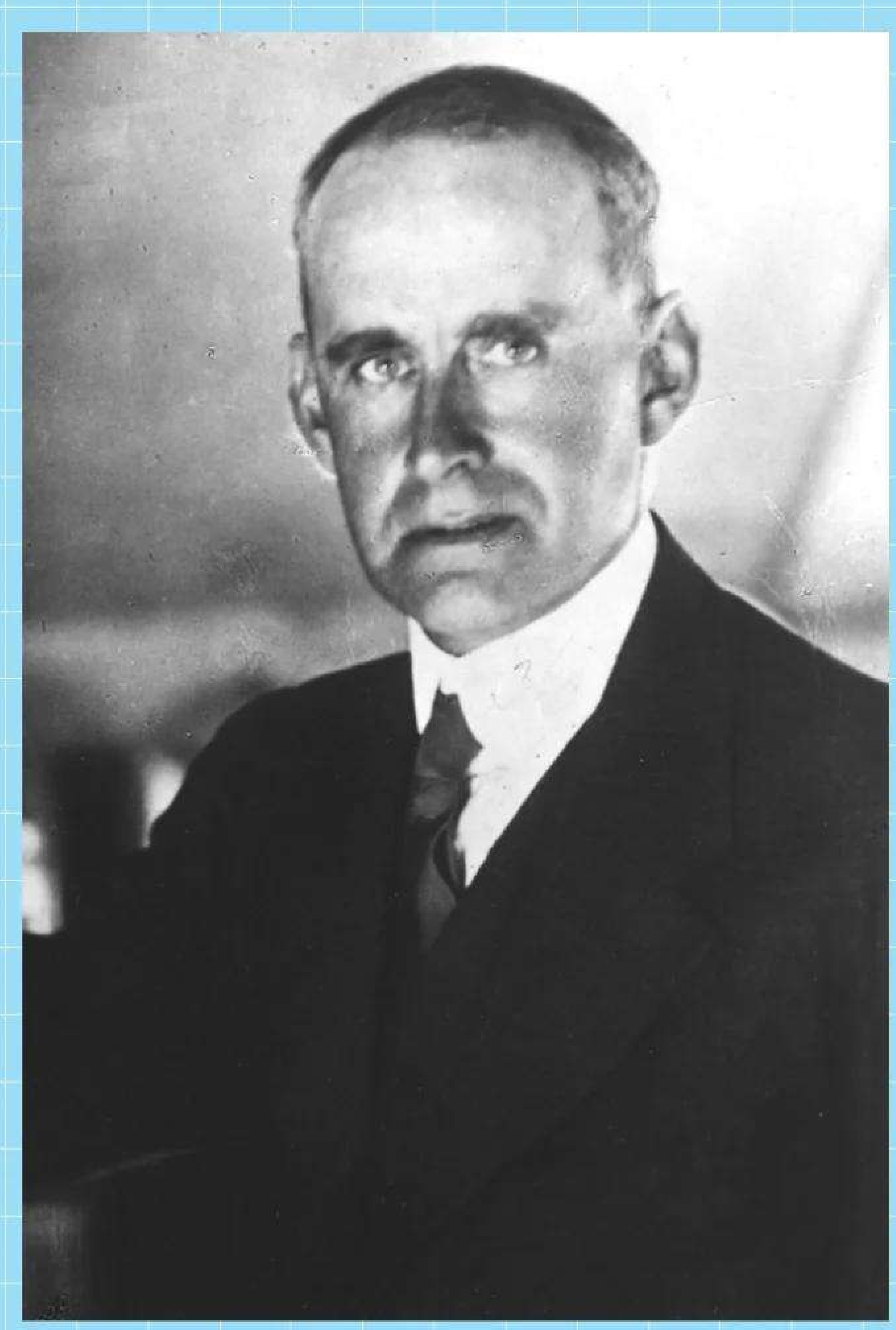
Born into a Quaker family in Kendal in northern England, Eddington went on to become an astronomer, physicist and mathematician who became known for his popular expositions and interpretations of Einstein's theory of relativity.

In 1919, three years after Einstein published his theory of general relativity, Eddington conducted an expedition to observe the total solar eclipse of 29 May 1919 on the Island of Principe off the west coast of Africa. The aim of this expedition was to make the first empirical test of Einstein's theory: the measurement of the deflection or bending of light by the Sun's gravitational field.

During the eclipse Eddington took pictures of several stars in the Hyades cluster whose line of sight from the Earth was near the Sun's location in the sky at that time of year. Only during a solar eclipse is this effect noticeable, when the sky is dark enough to observe stars that are normally obscured by the Sun's brightness.

Einstein's theory of general relativity asserts that stars with light rays passing near the Sun would appear to be slightly shifted as their light had been curved by its gravitational field. Eddington's observations confirmed Einstein's theory as evidence of general relativity over the Newtonian model.

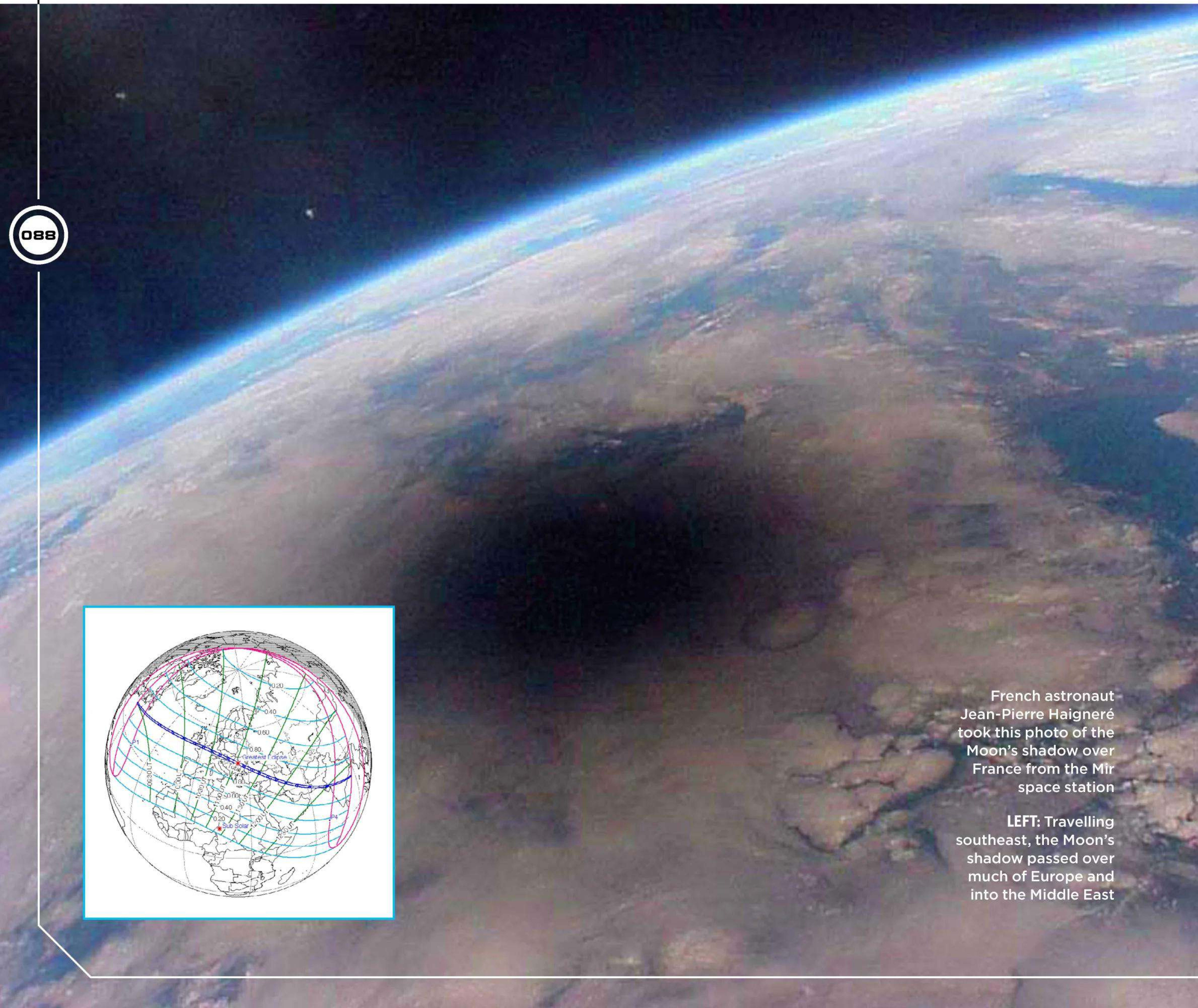
In 1920, Eddington published his findings from the total solar eclipse and the news made headlines internationally. Eddington then embarked on a campaign to popularise relativity and the solar eclipse expedition as pivotal moments in the development of science around the globe.



A MESSAGE FROM THE GODS

A blood Moon eclipse looms over the Temple of Apollo in Corinth, Greece, on 27 July 2018.

1999: THE ECLIPSE OF THE MILLENNIUM



French astronaut Jean-Pierre Haigneré took this photo of the Moon's shadow over France from the Mir space station

LEFT: Travelling southeast, the Moon's shadow passed over much of Europe and into the Middle East

At the height of Y2K fever, the skies turned dark over Europe and the Middle East in a rare and spectacular event

WORDS NIKOLE ROBINSON

Special eclipse glasses were sold in their thousands in countries able to view the event

Not many people live to see the turn of a century, let alone a millennium, and even fewer witness a total solar eclipse during their lifetime. A combination of these events in 1999 meant people were in for a real once-in-a-lifetime experience.

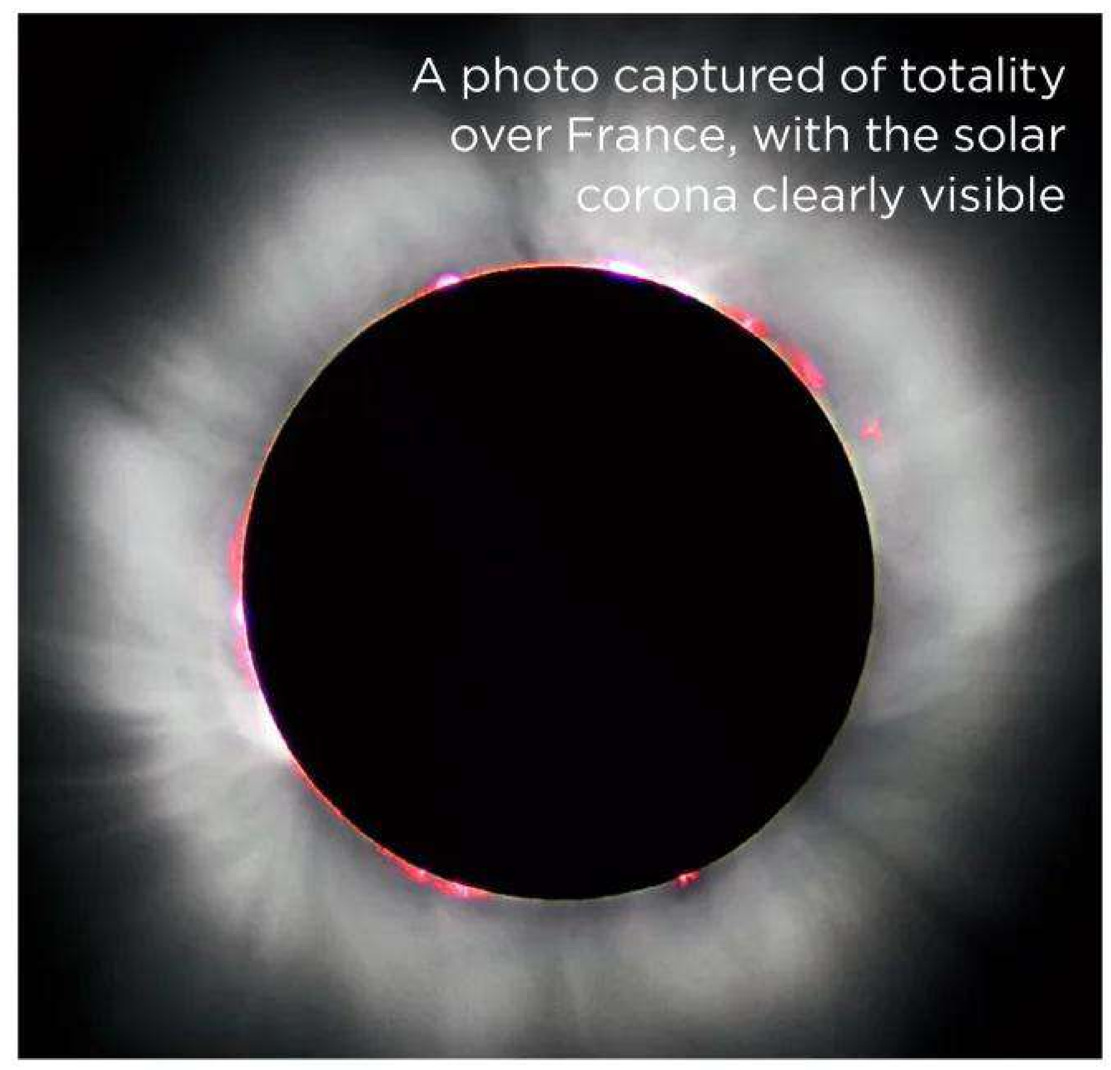
Though there are between two and five solar eclipses in any given year depending on the positions of the Sun and Moon, a total solar eclipse only occurs every 18 months or so, and in many cases totality passes over the sea, unpopulated or inaccessible areas. However, the path of the 11 August 1999 eclipse was special in that it passed over much of Europe, continuing over the Middle East and India, meaning it was easily viewable for millions of people. As such, it became one of the most watched eclipses in history.

Rising over the Atlantic at dawn, the Sun and Moon travelled eastward together, with totality observed from the southeastern tip of the UK, northern France, southern Belgium, Luxembourg, southern Germany, Austria, Hungary and northern Serbia (Yugoslavia at the time). The point of maximum totality was observed in Romania, near the small village of Ocnele Mari and the town of Râmnicu Vâlcea. After maximum, the eclipse continued its journey into Bulgaria, sweeping across the Black Sea, Turkey, northeastern Syria, northern Iraq, Iran, southern Pakistan and Srikakulam in India before its end in the Bay of Bengal. Though only certain regions were positioned in the narrow 112-kilometre (70-mile) shadow of the Moon, a partial eclipse was visible from further afield, covering most of Europe, Scandinavia, North Africa and parts of China.

This was the first total solar eclipse visible from the UK since 29 June 1927, so excitement was palpable across the nation. But in typical British fashion, grey skies stole the show. With only parts of Devon and Cornwall experiencing full coverage, local councils expected tourists to overwhelm the southeast, increasing police presence as a precaution, but this wasn't the case. Perhaps due to cloudy weather, many eclipse-viewing sites were well under capacity. Though only glimpses of totality could be seen through the occasional gap in the clouds, the crowds that had gathered still enjoyed the disorientating feeling of being plunged into darkness in the day. Countrywide, people left offices and teachers took children into playgrounds to marvel at the event through special eclipse glasses. Though totality was obscured in most of the south, much of the country had clear skies, and citizens were able to see up to 80 per cent of the Moon's disc cover the Sun. With the next total solar eclipse over the UK not until 23 September 2090, everyone made the most of this truly unique experience.

As the eclipse passed over Eastern Europe there were varied reactions to the spectacle. Unlike the crowded streets of Cornwall, Paris and Munich, in Serbia the towns and cities were eerily empty; in the lead-up to the event, the government advised people to stay inside due to concerns over public health caused by 'changes in the atmospheric environment', with its people taking heed and watching coverage on television instead.

In Romania the display was met with jubilation but also superstition. The capital city of Bucharest was directly in the path of totality, experiencing two minutes and 23 seconds of darkness as the Sun was hidden from view. In Romanian mythology, an eclipse is caused by demons eating the Sun, who must be scared away. In keeping with this ancient belief, a giant cross was burned in the capital under the darkened sky as crowds cheered, the fire thought to cleanse the evil of the eclipse.



A photo captured of totality over France, with the solar corona clearly visible

In the Islamic world, the obstruction of sunlight was seen as a doomsday warning, met with both awe and dread. Muslim clerics advised their followers to stay at home and pray for the Sun's return, and many flocked to mosques for special worship. As it is considered un-Islamic to cause yourself harm, looking at the Sun was heavily discouraged, though many mosques kept windows open so that the sudden darkness and return to light could be observed during prayer.

In India, religion also affected reactions, with Hindu mythology stating eclipses are caused by a vengeful demon and are thus precursors to disaster. Here, all work is stopped, nothing is eaten or drank and prayers are said.

It seems that religious or not, an eclipse invokes a feeling of spirituality over any observer, and the majesty of the 1999 eclipse certainly did just that.

"WITH THE NEXT TOTAL SOLAR ECLIPSE OVER THE UK NOT UNTIL 2090, EVERYONE MADE THE MOST OF THIS TRULY UNIQUE EXPERIENCE"

HOW FLAT-EARTHERS EXPLAIN LUNAR ECLIPSES

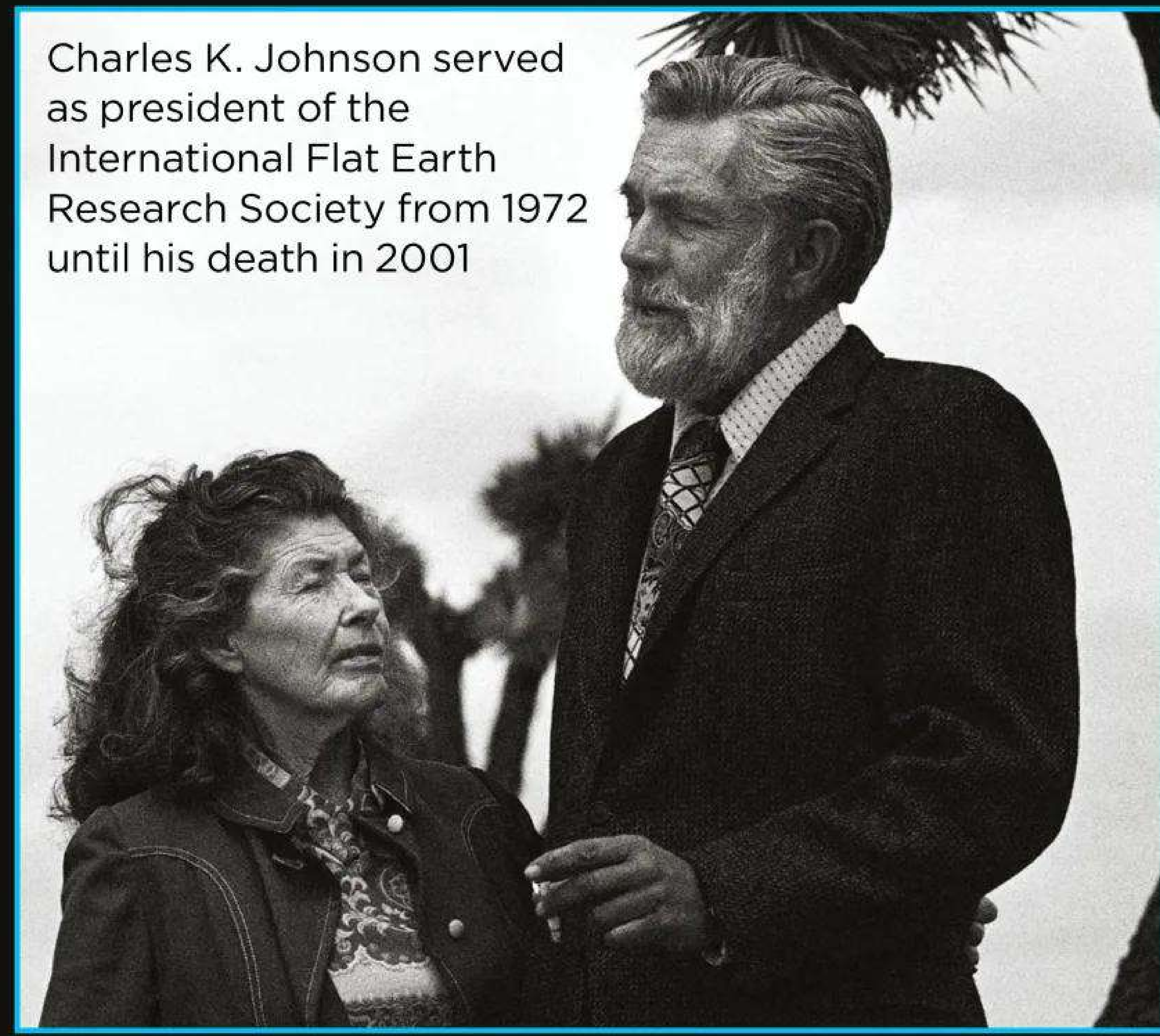
Despite the well-researched science behind lunar eclipses, a fringe group of round-Earth deniers have created their own theory

WORDS HANNEKE WEITERING

The blood-red colour of the Moon during a total lunar eclipse may be difficult to explain without a basic understanding of orbital mechanics, but flat-earth conspiracy theorists have come up with a very creative explanation of this phenomenon that enables them to circumvent science.

Our natural satellite appears red during lunar eclipses for the same reason that sunrises and sunsets appear that shade here on Earth: because sunlight is scattered as it passes through the atmosphere. According to flat-earth conspiracy theorists, this astronomical phenomenon — known as a total lunar eclipse — is actually a rare opportunity to catch a glimpse of a mysterious "shadow object" that orbits the Sun and occasionally passes in front of the Moon from our point of view here on an allegedly pizza-shaped Earth.

Although flat-earthers believe our planet resembles a pancake, they



Charles K. Johnson served as president of the International Flat Earth Research Society from 1972 until his death in 2001

Rapper B.O.B. is one of many celebrity flat-earthers

surprisingly seem to have come to the consensus that the Sun and Moon are spherical objects. However, these theorists posit that both the Sun and the Moon orbit Earth's north pole, hovering directly above the pancake and never passing around to the other side. If that were true, however, lunar eclipses as we know them could not happen, because the Moon must be on the opposite side of the Earth from the Sun for such an event to occur.

You'd think this would be a slam dunk for anyone who argues that the Earth is round, but flat-earthers are nothing if not inventive, and they have fabricated an 'explanation' for the shadow seen on the Moon during an eclipse.

In a post on The Flat Earth Wiki, a website run by The Flat Earth Society (which is based in Tennessee), the conspiracy theorists offer no description of the so-called "shadow object", but the writers claim this elusive figure causes all lunar eclipses. Oh, and it's totally invisible when it's not in front of the Moon.

"The shadow object is never seen in the sky, because it orbits close to the Sun," says The Flat Earth Wiki. Even though the tiny, innermost planet of our solar system, Mercury, can be seen close to (and occasionally in front of) the Sun, The Flat Earth Wiki falsely asserts that "we are never given a glimpse of the celestial bodies which appear near the Sun during the day".

If nothing else, The Flat Earth Wiki does provide a description of the mysterious proposed object's orbit, stating that it's tilted about 5.15 degrees to the Sun's orbital plane. Coincidentally, in reality this is the angle at which the Moon's orbit is tilted with respect to Earth's orbit.

The Flat Earth Society do not proffer the mathematical calculations by which they arrived at this number, which seems more likely to have been 'borrowed' from real astronomers' calculations than to have been derived from scratch. The page also states that "there is a possibility that the shadow object is a known celestial body which orbits the Sun; but more study would be needed to track the positions of Mercury, Venus and the Sun's asteroid satellites and correlate them with the equations for the lunar eclipse before any conclusion could be drawn".

Astronomers have already charted the orbits of all the planets for the foreseeable future, and none of them will come in between Earth and the Moon any time soon (or ever). Clearly, The Flat Earth Society's explanation of the lunar eclipse is flat-out wrong, and it doesn't end there.

The wiki page also firmly states the Society's belief in what it calls a "Space Travel Conspiracy" before claiming, "The purpose of NASA is to fake the concept of space travel to further America's militaristic dominance of space."

Despite all of the evidence to the contrary, the 500 or so members of the Flat Earth Society (which was founded in 1956) will likely continue to affirm that we do in fact inhabit a floating disc, one ringed with a gigantic ice wall.

THE BLOOD MOON PROPHECIES

The ramblings of devoutly religious pastors or an ominous premonition?

WORDS BEE GINGER

The name itself evokes awe and uncertainty, rather like the title of a horror movie. But in 2013, prophecies relating to a series of impending eclipses and their possible significance were preached to captivated audiences by Christian evangelical pastors John Hagee and Mark Biltz. Both believed there to be a correlation between key historical world events and eclipses occurring on Jewish holy days. They claimed that God, the Master Timekeeper, communicated with his flock on Earth through the use of heavenly bodies, particularly at a time when significant lunar and natural events were due to take place.

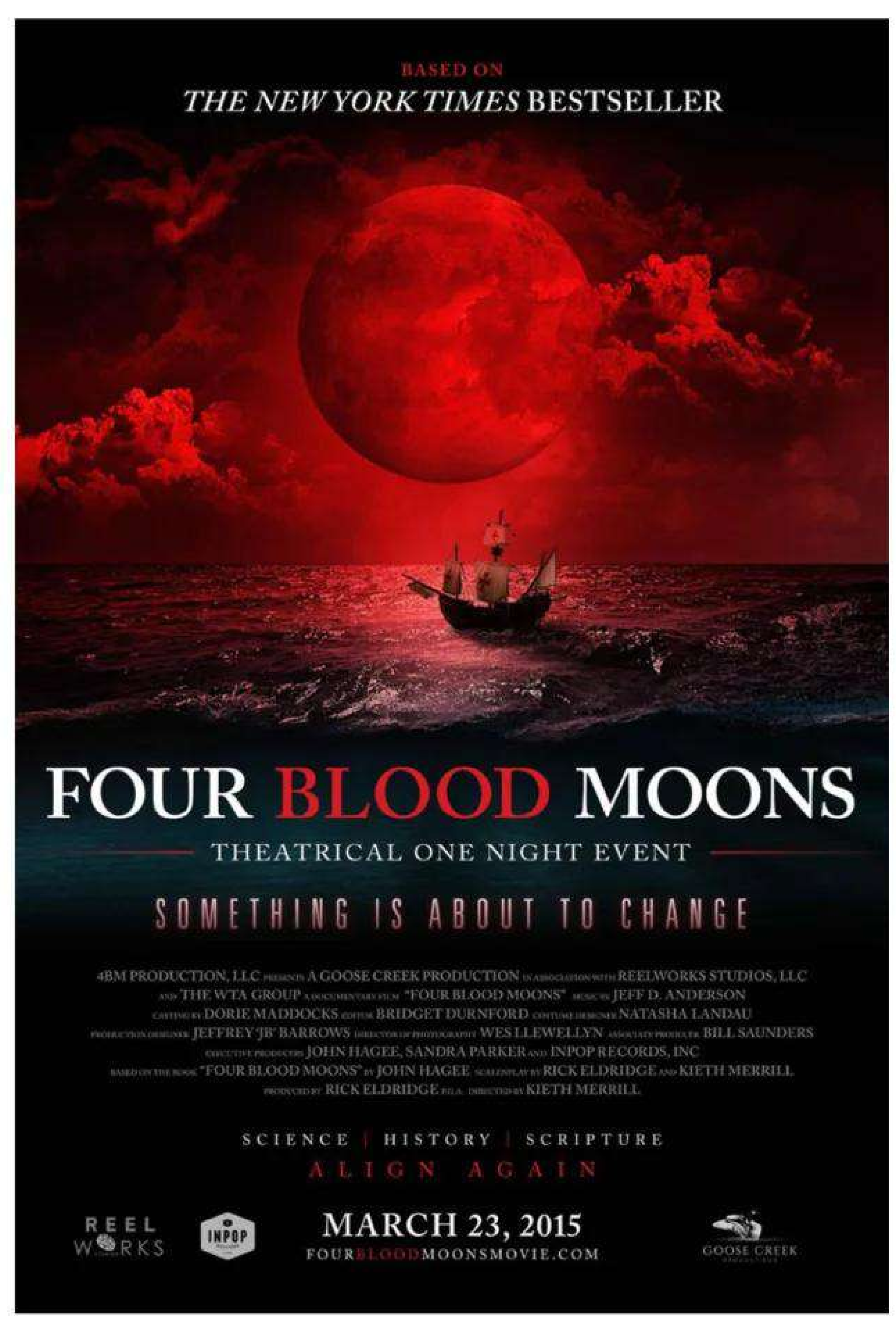
There were to be four consecutive blood moons across an 18-month period, the first on 15 April 2014. This is called a tetrad, which comes from the Greek word *tetras*, meaning group of four. All four were total lunar eclipses, and each one would sport a reddish glow due to something known as Rayleigh scattering. This is when particles scatter light through the Earth's atmosphere, and it's the reason the sky is blue and the Sun has a yellow-red hue.

Granted, a tetrad is quite rare and definitely something to behold, but it was the frequency and colour of the impending eclipses that prompted theorists to interpret them as a sign of dark times ahead. None were more vocal in their warnings than the aforementioned preachers who, having referenced their trusty Bible, came out with numerous quotations from the holy book. One forboding line from Joel 2:31 reads, "The Sun shall be turned into darkness, and the Moon into blood, before the great and terrible day of the Lord." The New Testament echoes a similar premonition in Acts 2:20, where the following is written: "The Sun shall be turned into darkness, and the Moon into blood, before the great and notable day of the Lord."

Hagee believed that something ominous would happen to the nation of Israel as a result of the tetrad, particularly as the moons coincided with both Jewish Passover in April and the Feast of Tabernacles in October. Holy days observed by the Jewish community

Hagee is the founder and chairman of John Hagee Ministries, which broadcasts sermons in the U.S. and Canada

RIGHT: Hagee wrote the best-selling book *Four Blood Moons*, which inspired a film



"THE SUN SHALL BE TURNED INTO DARKNESS, AND THE MOON INTO BLOOD, BEFORE THE GREAT AND TERRIBLE DAY OF THE LORD"

Many civilisations believed a big cat (such as a jaguar) attacks the Moon during an eclipse, hence the blood-red colour

revolve heavily around the lunar calendar. However, in his book titled *Four Blood Moons: Something is About to Change*, Hagee claims that historically when a tetrad has fallen over Jewish holy days something "world changing" and hugely traumatic has happened to Israel.

The facts don't support this argument, as historically this has not been the case. According to Fred Espenak, NASA's eclipse expert, there were no tetrads at all between 1600 and 1900.

Not one to be dissuaded by science or popular opinion, Hagee, founder of the Cornerstone Church in San Antonio, Texas, went on to plan a specialised event to be aired on the Global Evangelism Television channel. He explained that he had discovered an astronomical pattern that had enabled him to predict when the next tetrad would occur and how it would coincide with the end times and the second coming of Christ. He firmly believed that 15 April 2014 would mark the beginning of the end of days, when Christ would appear in the skies to summon both living and dead Christians up to heaven, thereby saving them from a wave of destruction on Earth that would culminate in the Battle of Armageddon. Quite some primetime viewing!

Hagee stated that God had been sending signals to Earth but nobody had been picking them up until now. In one of his sermons he proclaimed to his congregation, "When you see these signs, the Bible says, lift up your head and rejoice, your redemption draweth nigh."

Hagee wasn't the only one to put his dire warnings down on paper; Mark Biltz penned *Blood Moons: Decoding the Imminent Heavenly Signs*, while Mark Hitchcock, another pastor who hailed from Oklahoma, made his contribution with *Blood Moons Rising: Bible Prophecy, Israel, and the Four Blood Moons*.

Once the Moon has been completely submerged in the shadow of the Earth it turns a coppery, reddish hue

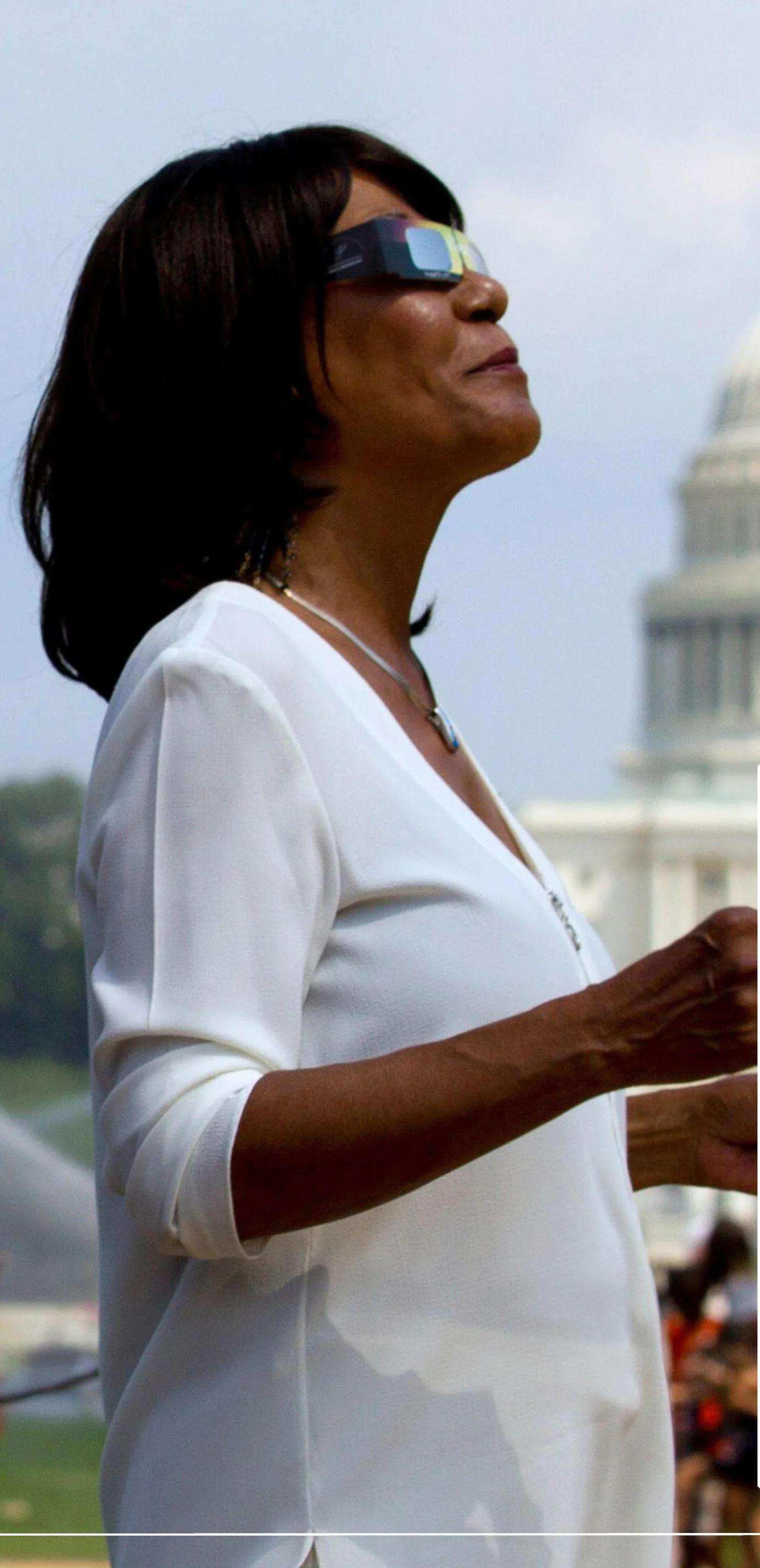
Despite also being prophesied in the Book of Revelation ("And I beheld when he had opened the sixth seal, and, lo, there was a great earthquake; and the Sun became black as sackcloth of hair, and the Moon became as blood"). the term 'blood moon' does not feature in the Bible, so it is curious why these preachers chose to refer to it by this name.

It will be interesting to see if further prophecies will be bestowed upon future eclipses, as there will be six more tetrads before the year 2100.

SECTION 3

2024 AND BEYOND

WHERE TO SEE THE 2024 ECLIPSE



This April, parts of the U.S. will witness a total solar eclipse. Here's a guide to where it will be visible

WORDS CHARLES GINGER

A total solar eclipse is a rare and magical experience for us Earthlings, largely because many of them occur over the vast oceans that cover approximately 70 per cent of our planet's surface. So when the opportunity arises to watch this mesmerising aligning of the Earth, Moon and Sun there is an understandable sense of excitement – and there's one coming on 8 April of this year.

While it won't be visible to the majority of the global population, a fortunate few (well, few million) in North America will be able to observe the eclipse in parts of Canada, the United States and Mexico.

The 185-kilometre-wide (115-mile) path of totality will be passing over 15 U.S. states (including small parts of Tennessee and Michigan), and here is where the Moon's shadow will fall across America.

13:27 01

TEXAS

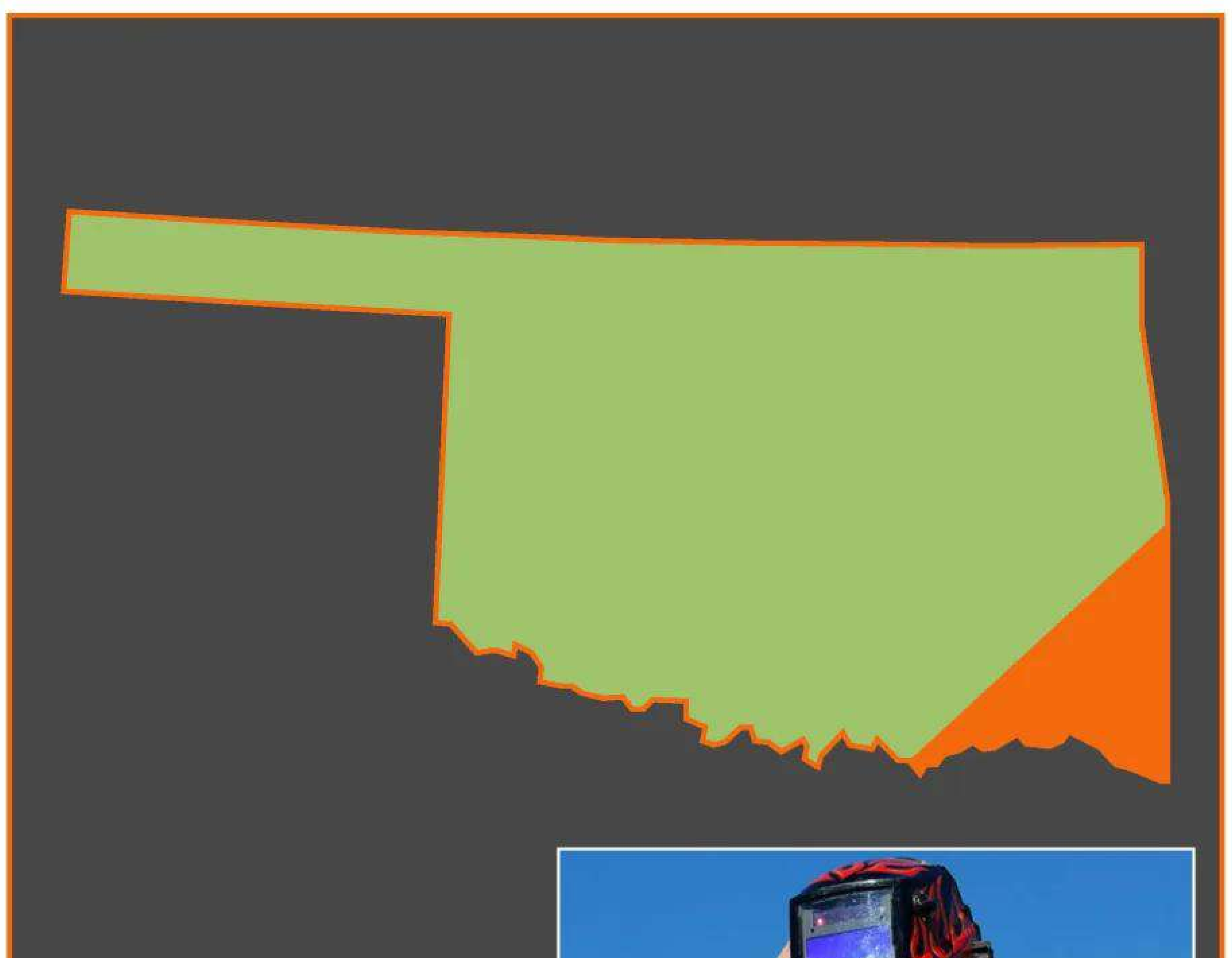
TIME OF TOTALITY

This state will be in totality from 1:27 p.m. to 1:49 p.m. **Partial eclipse** will begin at 12:09 p.m.

ABOVE: Police officers in Austin watch the annular solar eclipse on 14 October 2023

13:43 02

OKLAHOMA



TIME OF TOTALITY

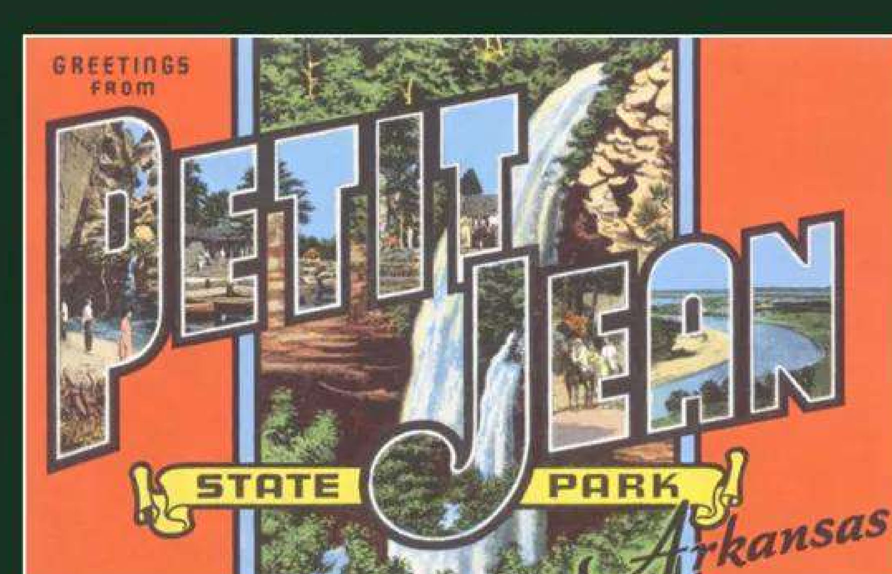
This state will be in totality from 1:43 p.m. to 1:51 p.m. **Partial eclipse** will begin at 12:25 p.m.

13:45 03

ARKANSAS

TIME OF TOTALITY

This state will be in totality from 1:45 p.m. to 2 p.m. **Partial eclipse** will begin at 12:28 p.m.



13:53 | 04

MISSOURI

TIME OF TOTALITY

This state will be in totality from 1:53 p.m. to 2:02 p.m. **Partial eclipse will** begin at 12:35 p.m.

ABOVE: The August 2017 solar eclipse unfolds over Jefferson City, Missouri

"THE 185-KILOMETRE-WIDE (115-MILE) PATH OF TOTALITY WILL BE PASSING OVER 15 U.S. STATES (INCLUDING SMALL PARTS OF TENNESSEE AND MICHIGAN)"

13:58 | 05

ILLINOIS

TIME OF TOTALITY

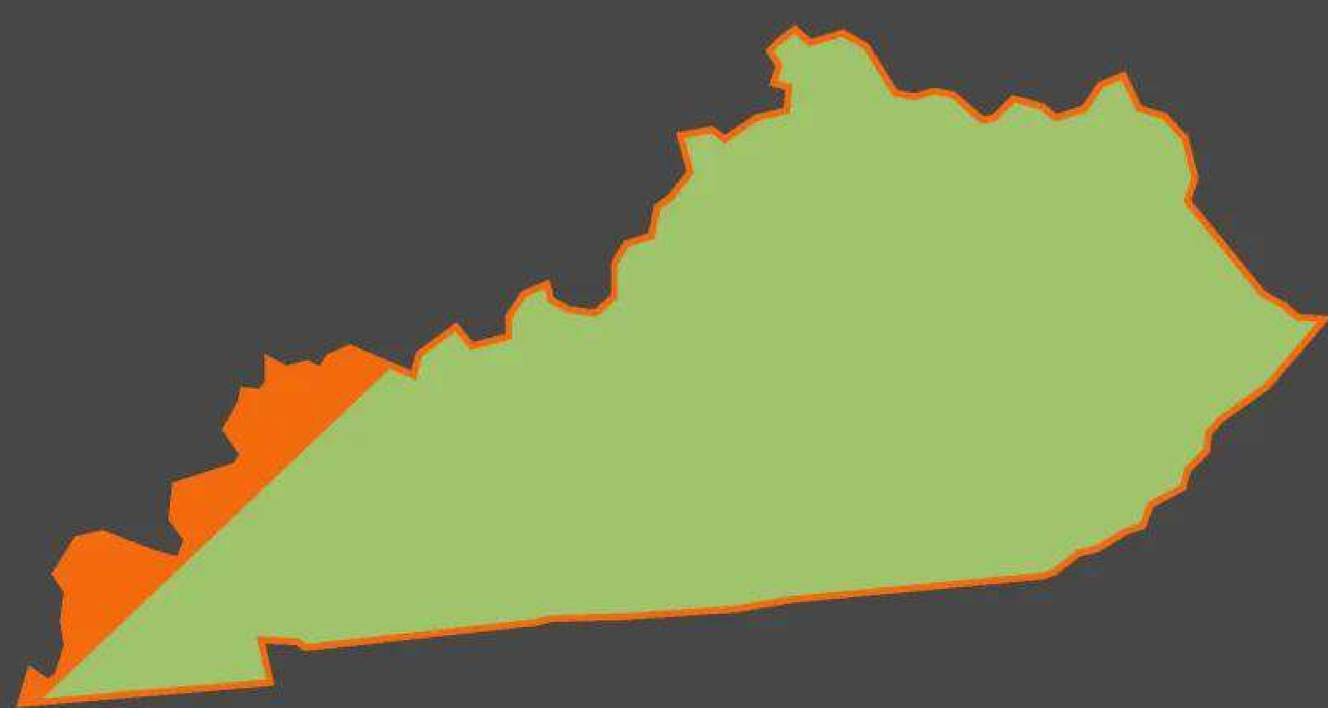
This state will be in totality from 1:58 p.m. to 3:07 p.m. **Partial eclipse** will begin at 12:41 p.m.

ABOVE: A sign outside Fort Massac State Park advertises the 2017 eclipse in Metropolis


HOLLYWOOD
GRIFFITH OBSERVATORY
SOLARAMA

13:58 06

KENTUCKY



TIME OF TOTALITY

This state will be in totality from 1:58 p.m. to 2:05 p.m. **Partial eclipse** will begin at 12:40 p.m.

14:01 07

INDIANA

TIME OF TOTALITY

This state will be in totality from 2:01 p.m. to 3:12 p.m. **Partial eclipse** will begin at 12:44 p.m.

15:08 08

OHIO

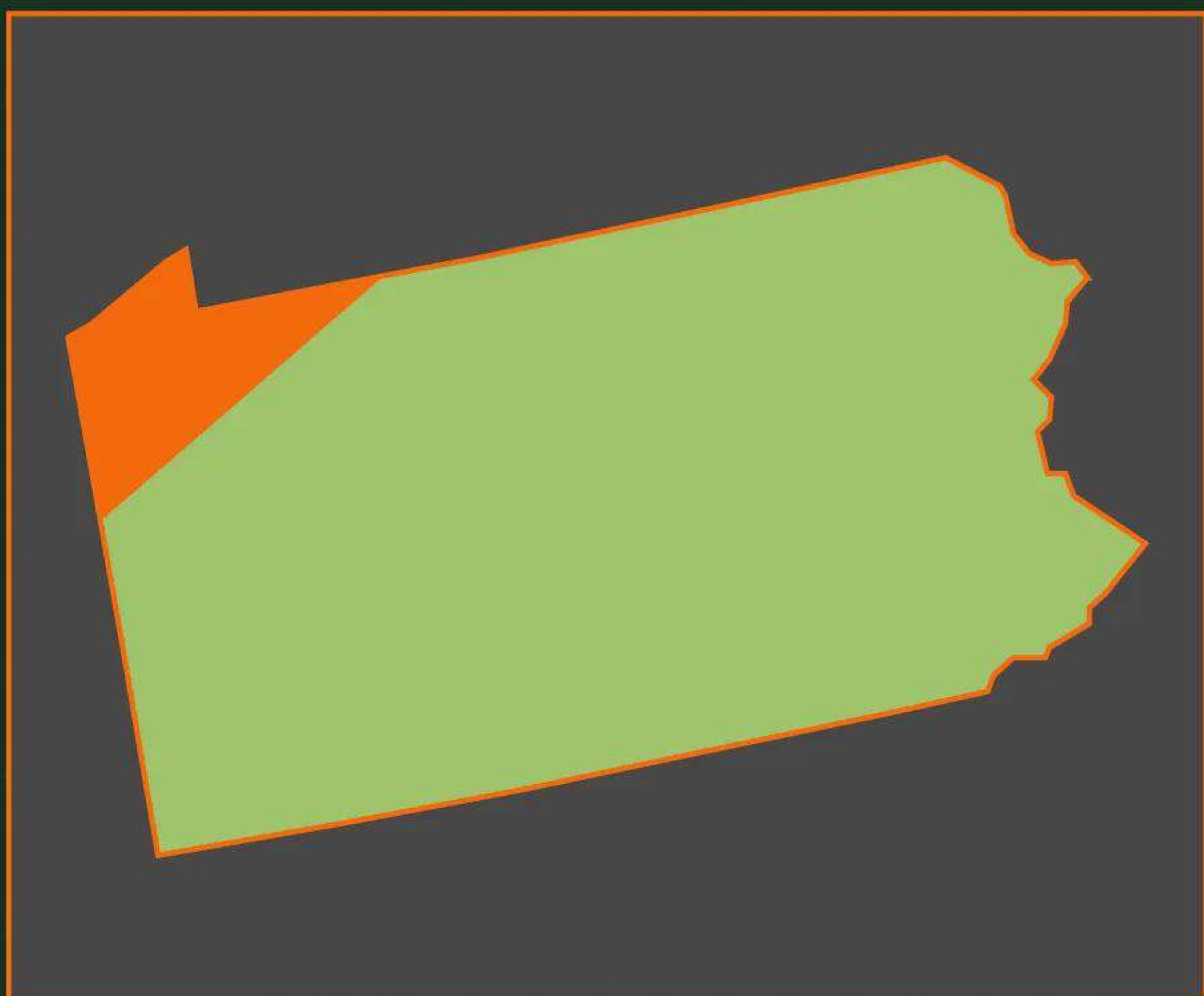
TIME OF TOTALITY

This state will be in totality from 3:08 p.m. to 3:19 p.m. **Partial eclipse** will begin at 1:51 p.m.

ABOVE: A young visitor enjoys the facilities at the Armstrong Air & Space Museum in Ohio

15:15 09

PENNSYLVANIA



TIME OF TOTALITY

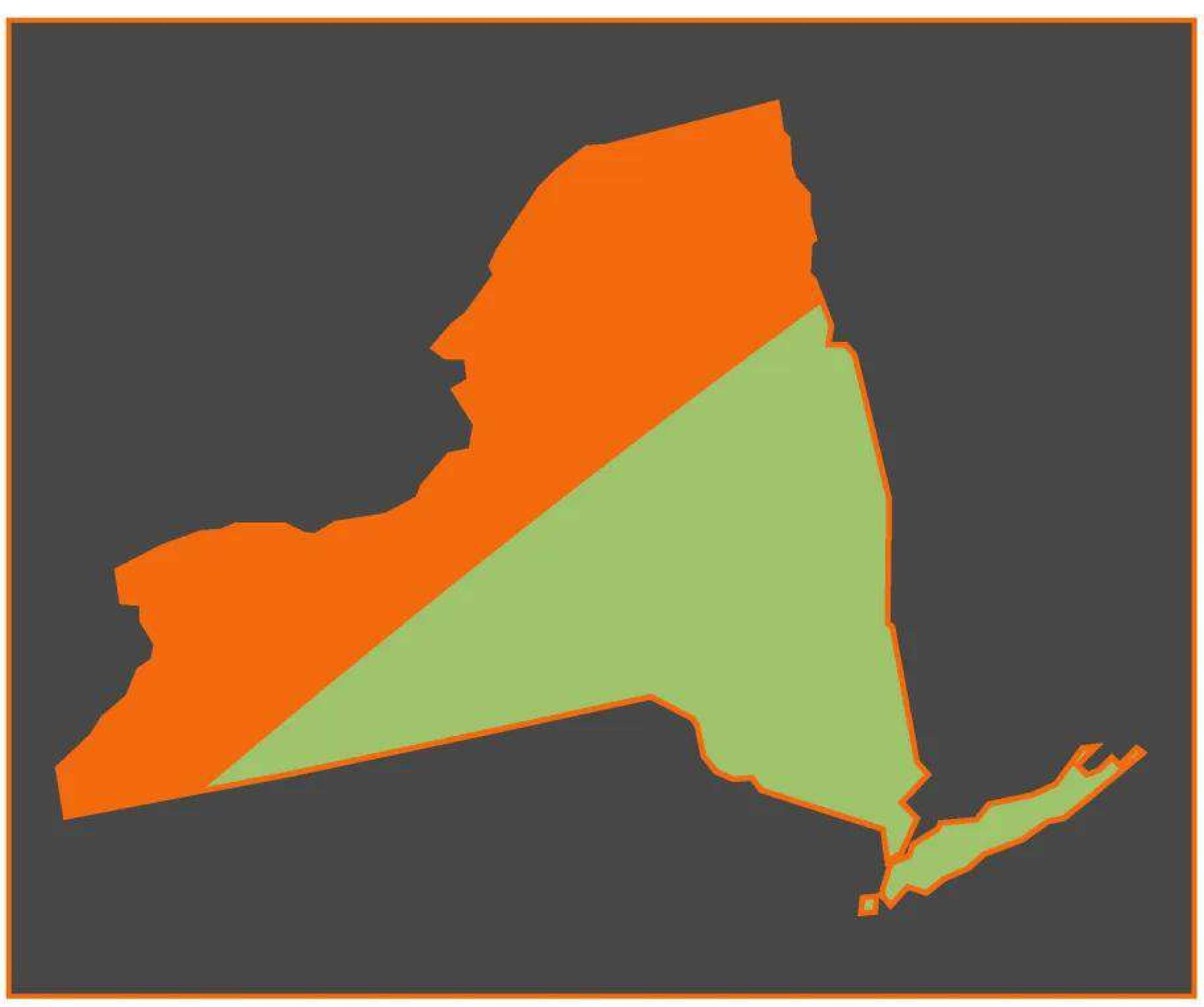
This state will be totality from 3:15 p.m. to 3:20 p.m. **Partial eclipse** will begin at 2:00 p.m.

ABOVE: This image shows the Moon being eclipsed by Earth above Warminster

THE ECLIPSE WILL ALSO BE VISIBLE IN SOUTHERN ONTARIO, QUEBEC, NEW BRUNSWICK, PRINCE EDWARD ISLAND AND CAPE BRETON, AS WELL AS PARTS OF NORTHERN MEXICO

15:16 10

NEW YORK STATE



TIME OF TOTALITY

This state will be in totality from 3:16 p.m. to 3:29 p.m. **Partial eclipse** will begin at 2:02 p.m.

ABOVE: A full blood Moon sets over the Empire State Building in Manhattan, New York

13:25 | 11

VERMONT

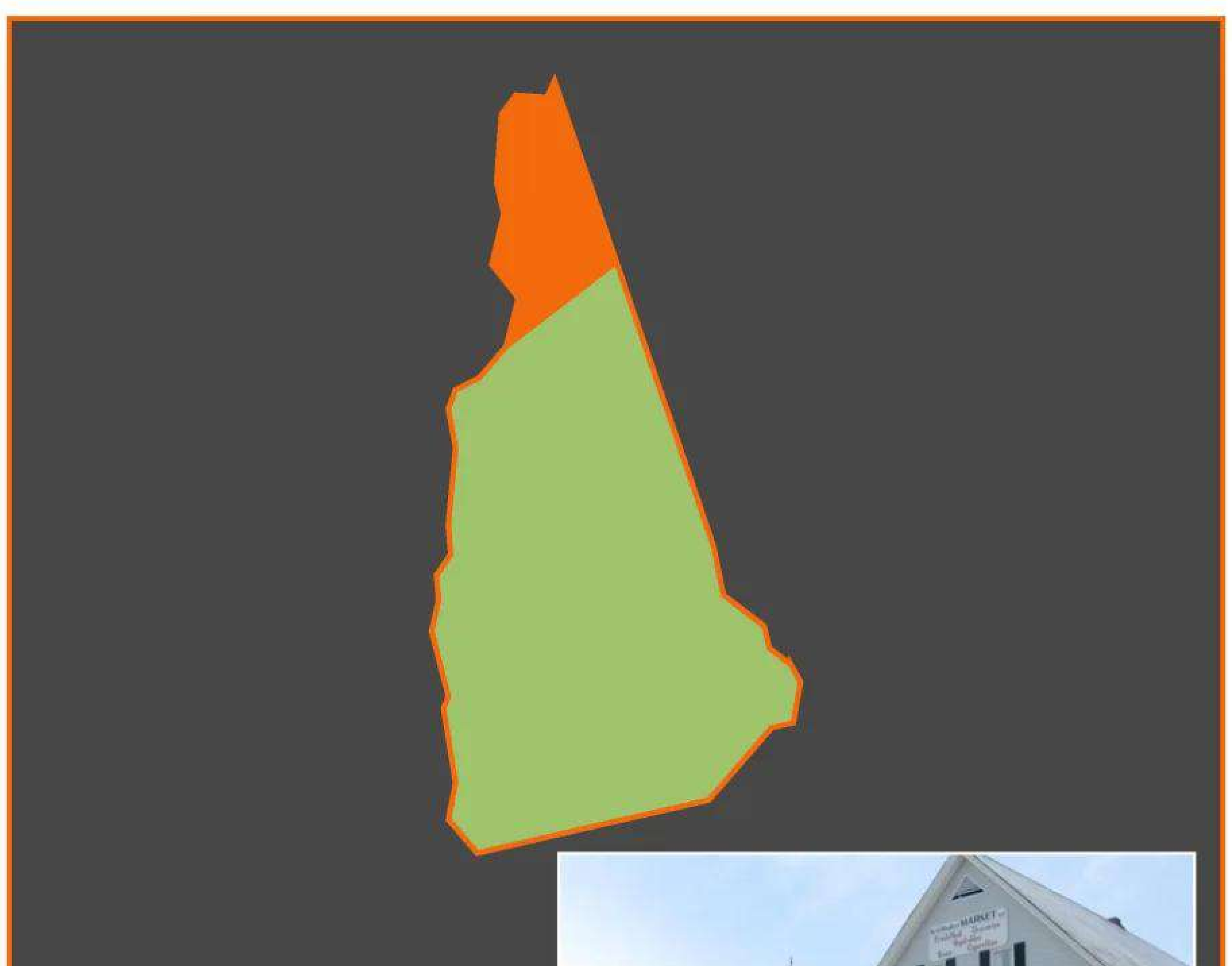
TIME OF TOTALITY

This state will be in totality from 3:25 p.m. to 3:31 p.m. **Partial eclipse** will begin at 2:13 p.m.

ABOVE: The 2024 total solar eclipse will pass over the Vermont State House in Montpelier

15:28 | 12

NEW HAMPSHIRE

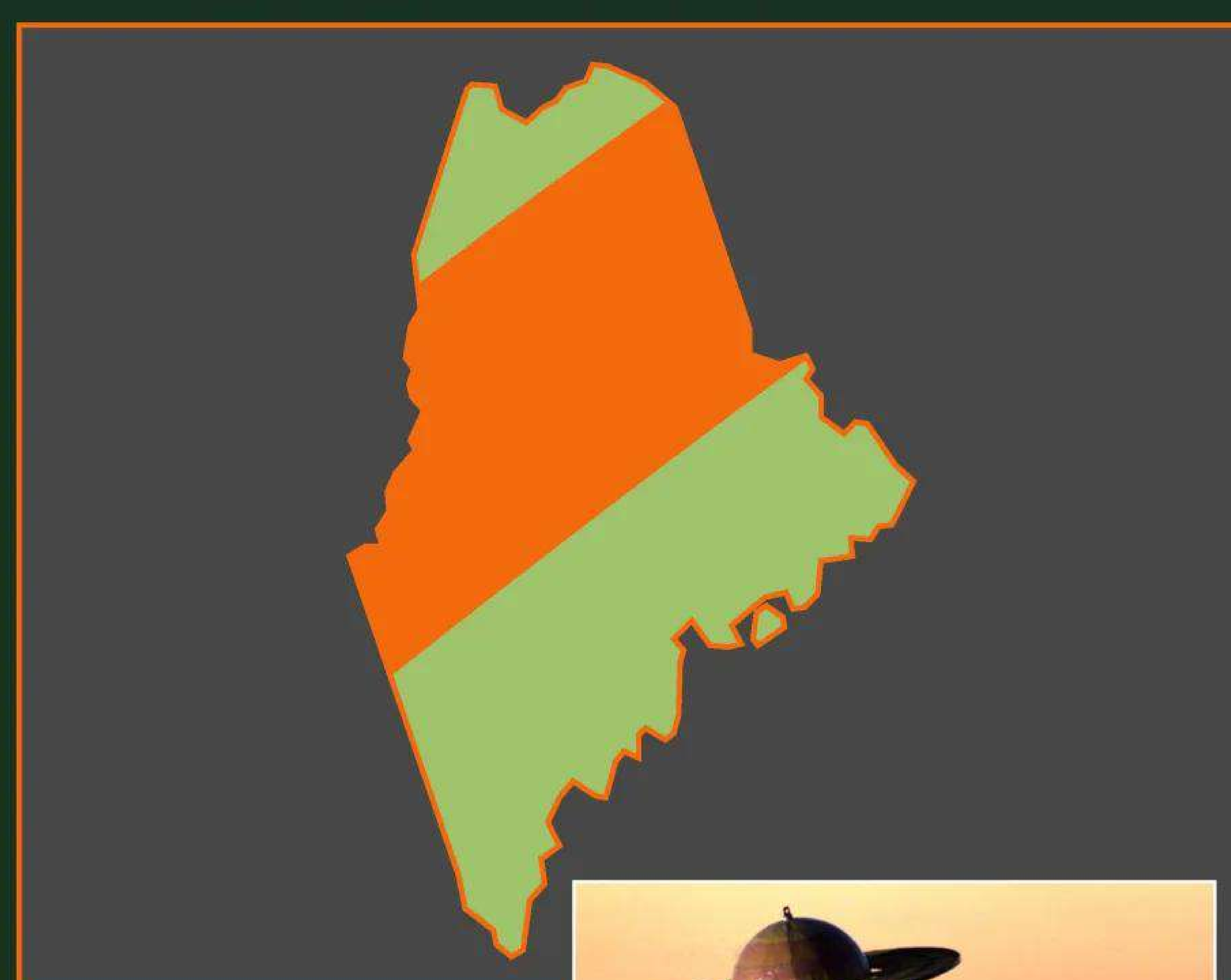


TIME OF TOTALITY

This state will be in totality from 3:28 p.m. to 3:32 p.m. **Partial eclipse** will begin at 2:16 p.m.

15:28 | 13

MAINE



TIME OF TOTALITY

This state will be in totality from 3:28 p.m. to 4:35 p.m. **Partial eclipse** will begin at 2:17 p.m.

HOWLING AT THE MOON

This captivating image provides a panoramic view of various phases of the super blood wolf Moon on 21 January 2019.

OBSERVING AN ECLIPSE

Whether you're looking to capture the moment or just want to watch, we have the kit that's perfect for enjoying an eclipse

With the Sun being a dangerous object to look at, many might shy away from solar observing. However, provided you have the right kit and you ensure that you take care when viewing the incredibly bright surface, looking at our nearest star can be a truly breathtaking experience. Whether you have a solar telescope or a pair of glasses made especially for the event, with the total solar eclipse on the way all protected eyes will be on the Sun this April (if you're fortunate enough to be living somewhere in the path of totality of course).

Given that it's a great astronomical event — and unless you know a keen solar observer who will allow you to use their instrument — it's tempting to rush out and buy a solar telescope. But a decent solar telescope will cost a few hundred dollars, an expensive price tag if you don't plan to use it to observe the Sun — along with its stunning solar prominences, filaments and sunspots — after the eclipse.

Even if you do come across a relatively cheap solar instrument, you should err on the side of caution and ask yourself if you are purchasing from a reputable dealer. Looking through a poorly manufactured or damaged instrument is a mistake that could cost you your eyesight. Remember also that unless you're interested in looking closely at the Sun's surface, then you are better off watching the eclipse with a wider field of view, either by using the projection method or a pair of specially made eclipse glasses.

Many will want to capture the eclipse in a photograph, and just as you should take care when observing it, caution is required if you wish to image this rare event. The good news is that pretty much any type of camera can be used provided it is fitted with a solar filter, but get one that has a fairly long focal length in order to produce an image that's as large as possible.

Have a browse of our recommended kit. You'll find that this equipment is of high quality and, most importantly, is incredibly safe to use.

REMEMBER!

If you're looking to purchase kit for the eclipse, you should ensure that you buy it from well-known, reputable dealers and manufacturers such as Baader, Coronado, Lunt and Orion. If you're unsure about using anything you have purchased then you should avoid using it for watching the eclipse.

SUN PROJECTOR KIT

Cost: $23 (approx.)
From: Green Witch

Practical and easy to set up, this instrument projects the Sun onto a viewing screen and allows you to view the solar eclipse safely. The optics consist of an achromatic glass lens as well as two convex mirrors, and the projector can be adjusted from 0 to 90 degrees in order to locate the Sun's position in the sky securely and effectively. Ideal for introducing children to the Sun.

LUNT SOLAR TELESCOPE

Cost: $1,083 (approx.)
From: The Astronomy Centre

Portable and easily mounted on a tripod, Lunt solar telescopes are versatile when it comes to looking at all manner of activity on the surface of our closest star. Catch the eruption of solar prominences and flares in the Sun's atmosphere as well as sunspots and granulation in complete safety and watch as the Moon's limb blocks them from view during the eclipse.

SOLOMARK BAADER SOLAR FILTER

Cost: $30 (approx.)
From: First Light Optics

An adjustable filter that's able to attach to a variety of apertures, the Solomark Baader solar filter allows you to safely observe the Sun without having to worry about risking your eyesight. Made to a high standard, just affix to the optical lens of your telescope to take in the surface details of our star in an eye-pleasing white colour and to get high-quality images with no distortion.

BAADER SOLAR ECLIPSE OBSERVING GLASSES

Cost: $3.80)
From: First Light Optics

Made from the highly regarded Baader AstroSolar safety film, you can watch the eclipse safely while observing it in real colour. Enabling you to take in the entire experience, the Baader foil reduces the intensity of the Sun's light by 99.999 per cent for a safe and memorable experience.

CORONADO CEMAX EYEPIECES AND BARLOW LENSES

Cost: $79.95 each
From: Telescope House

Specially designed for optimising views of the Sun in hydrogen-alpha wavelengths, the CEMAX series of eyepieces and Barlow lenses are multicoated to provide excellent contrast. At 1.25 inches (three centimetres) these eyepieces fit a wide selection of solar telescopes and provide good eye relief to ensure comfortable viewing. Available focal lengths are 12mm, 18mm and 25mm as well as a 2x Barlow lense to magnify your experience.

JARGON BUSTER

Sunspots
Sunspots are regions on the Sun's surface that appear dark. They are cooler than the surrounding areas by around 1,227°C (2,240°F).

Prominences
Prominences can be found above the Sun's visible surface, which is called the photosphere. They often appear as graceful loops that can stay suspended for a number of days.

Solar flares
Solar flares are characterised as sudden flashes of brightness released by the Sun's volatile surface as ejections of solar material.

Hydrogen-alpha
Hydrogen-alpha is a wavelength, and many astronomers view the Sun through this light in order to pick out its prominences and other features or activity. Hydrogen-alpha gives the Sun's surface its red-to-orange appearance.

Granulation
Granulation is the 'bubbly' or 'grainy' appearance of the Sun's face caused by currents bringing intense heat to the solar surface.

The focal length
The focal length is the optical length of an eyepiece or telescope. Telescopes with long focal lengths provide higher magnification with a given eyepiece. Focal length is almost always quoted in millimetres.

The aperture
The aperture is the diameter of a telescope's objective lens or mirror. The larger the size of a refractor or reflector's aperture, the greater the light-gathering ability of the instrument and therefore the more detail you can see on target objects.

HOW TO ADAPT YOUR TELESCOPE FOR SAFE ECLIPSE OBSERVATION

This simple technique is economical and only takes a few minutes

The safest, cheapest and easiest way to observe a solar eclipse using your telescope is by using the projection method. The projection method means that you don't have to risk your eyesight since the Sun will be projected onto a surface. Remember, looking at the Sun is extremely dangerous — more so through the added magnification of a telescope — so ensure that you take care when aligning your instrument. To avoid any accidents you should test your equipment with the Sun before the eclipse.

Of course, if you have a solar telescope, or you know someone who does, then you can simply point this specialised instrument at our star. If you would rather buy filters, then ensure that you purchase them from a reputable dealer.

In any case, if you are ever in any doubt whatsoever about the safety of the equipment you have purchased, you should always avoid using it. Nothing is worth risking your eyesight.

1 PREPARING THE CARD

Grab yourself a large piece of good-quality thick white card or poster board. When selecting this material, the thicker it is, the better, since this is where the Sun's light — and hence the image of the solar eclipse — will be projected. Make sure you have a good, sharp pair of scissors or a craft knife for cutting it and something to mark the lines out.

Imaging and filming the eclipse

It's easy to image or film the solar eclipse, however, you should ensure that a solar filter covers the lens of your camera throughout the event. Always test your equipment before the eclipse. If you're able to, try to set your camera to manual focus and exposure. Additionally, you should also ensure that your eyes are protected. Never look directly at the Sun without protection!

2 CUT AROUND THE EYEPIECE

To ensure optimum safety, you'll need to fit a piece of card around the eyepiece to block out any stray light. This will be used with your telescope. You should remember to remove the star diagonal before you begin and draw around the eyepiece you intend to use. Cut a hole in the card and place it around the eyepiece holder, making sure it fits snugly.

3 LOOK AFTER YOUR INSTRUMENT

It's no secret that the Sun is extremely hot, and it's crucial that you don't let your telescope overheat. If you feel that your telescope is extremely warm to the touch then you should move it out of the sunlight and into a shaded region to cool down. To ensure that danger is kept to a minimum make sure that your finderscope is capped.

4 ALIGNING YOUR TELESCOPE

Now you're ready to line up your telescope with the Sun. During the process you might find it tempting to look at the Sun but this should be avoided. While the Sun is large, ensuring that your telescope is pointing at it without the aid of a finderscope can be quite challenging. If you are having trouble then you should buy a Sun-finder to help you.

5 VIEW YOUR PROJECTION

Using the thick white board as a reference, you should focus your telescope until you get a sharp view of the Sun before the eclipse starts. Before the Moon makes its way across the Sun's surface you should be able to make out sunspots, some solar granulation and limb-darkening on the photosphere — also known as the visible surface of the Sun.

WILDFLOWER MOON

Carpeted in the golden hue of aspen trees, Mount Crested Butte in Colorado (regarded as the state's wildflower capital) reaches towards a blood Moon sky.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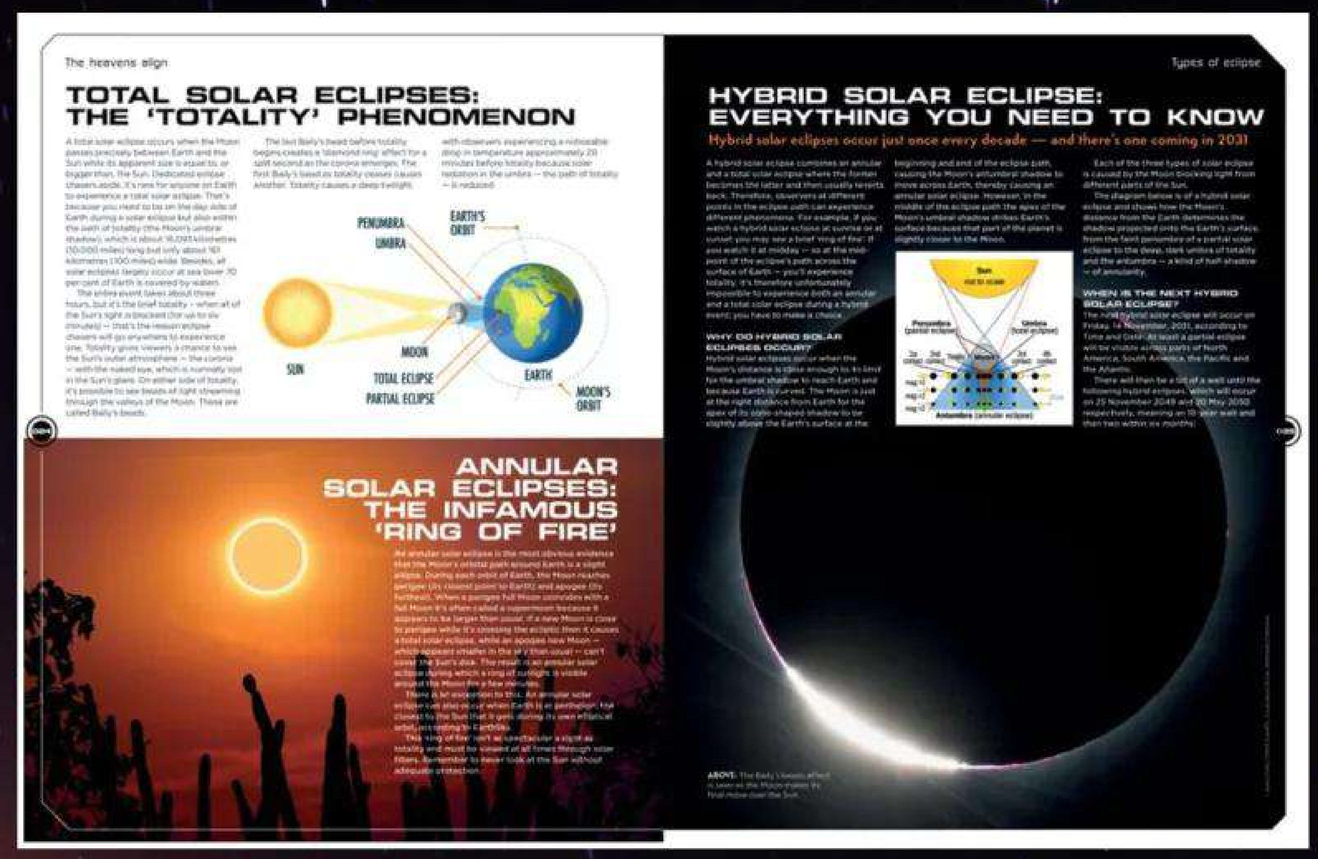
LEARN HOW TO SAFELY LOOK AT THE SUN

FROM THE MAKERS OF SPACE.com

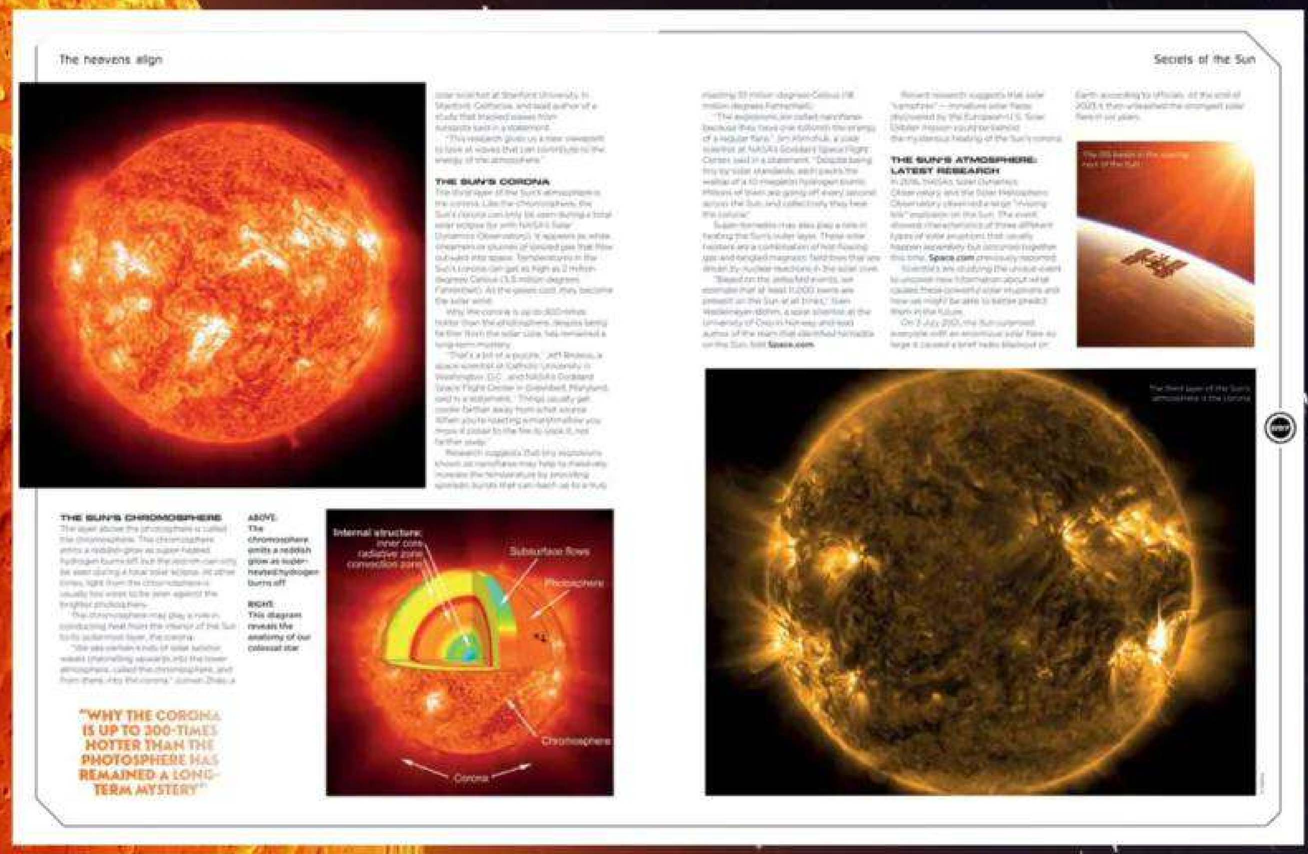
ECLIPSES

From the birth of the Moon to the future of stargazing, find out why the heavens align and how humankind has studied these mesmerising moments



TYPES OF ECLIPSE

Explore the anatomy of solar, lunar and hybrid eclipses



SECRETS OF THE SUN

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